ENHANCING COMPREHENSION IN OPEN DISTANCE LEARNING COMPUTER PROGRAMMING EDUCATION WITH VISUALIZATION

by

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I declare that

ENHANCING COMPREHENSION IN OPEN DISTANCE LEARNING COMPUTER PROGRAMMING EDUCATION WITH VISUALIZATION

is my own work and that all the sources that I have used or quoted have been indicated and acknowledged by means of complete references.

____ ________ ____15 October 2015____

SIGNATURE DATE

(Mrs)

Abstract

This thesis describes a research project aimed at improving the tracing skills of first-year programming students enrolled for an introductory C++ course at an open distance learning institution by means of a tutorial in the form of a program visualization tool to teach the students to draw variable diagrams. The research was based on the findings from the BRACElet project (Clear, Whalley, Robbins, Philpott, Eckerdal, Laakso & Lister, 2011). A design-based research methodology was followed.

To guide the process of developing the tutorial, a framework of 26 guidelines for developing and using visualization tools to teach programming was synthesized from the literature on computing education research CER, educational psychology and computer graphics. Guidelines were supplemented with reasons or explanations for their recommendation and considerations to be taken into account when using a guideline. The framework was enhanced by lessons learnt during the development and testing of the tutorial.

The tutorial was tested and refined during two implementation cycles. Both cycles included quantitative and qualitative investigations. All students registered for the introductory module received the tool with their study material. For the quantitative investigations, students completed a questionnaire after using the tutorial. Through the questionnaire biographical data was acquired, the manner in which students used the tutorial and how they experienced using it. The responses to the questionnaires were statistically analysed in combination with respondents' final marks. The statistical modelling indicated that the students' biographical properties (a combination of level of programming experience, marks obtained for Mathematics and English in matric and first-time registration for COS1511 or not), had the biggest impact on their final marks by far.

During the qualitative investigations students were eye tracked in a Human-Computer Interaction laboratory. The gaze replays in both cycles revealed that students' reading skills impacted largely on their success, connecting with the findings from the quantitative investigations.

Reflections on why the tutorial did not achieve its purpose; and why poor reading skills may have such a strong effect on learning to program, contribute some theoretical understanding as to how novices learn to program.

Keywords: Computer science education; teaching programming; novice programmers; introductory programming courses; distance teaching/learning; open-distance learning; program visualization; framework of guidelines for creating program visualizations; interactive tutorial; design-based research; educational psychology; eye tracking; reading skills; BRACElet

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Journal publications from this research

Schoeman, M., Gelderblom, H. & Smith, E. (2012) A tutorial to teach tracing to first-year programming students. *Progressio,* 34(3), 59-80. Available at: https://www.researchgate.net/publication/282610380_A_tutorial_to_teach_tracing_to_first-year_programming_students#full-text.

Schoeman, M., Gelderblom, H. & Muller, H. (2013) Investigating the Effect of Program Visualization on Introductory Programming in a Distance Learning Environment. *African Journal of Research in Mathematics, Science and Technology Education,* 17(1-2), 139-151. Available at: http://dx.doi.org/10.1080/10288457.2013.828408.

List of abbreviations and acronyms

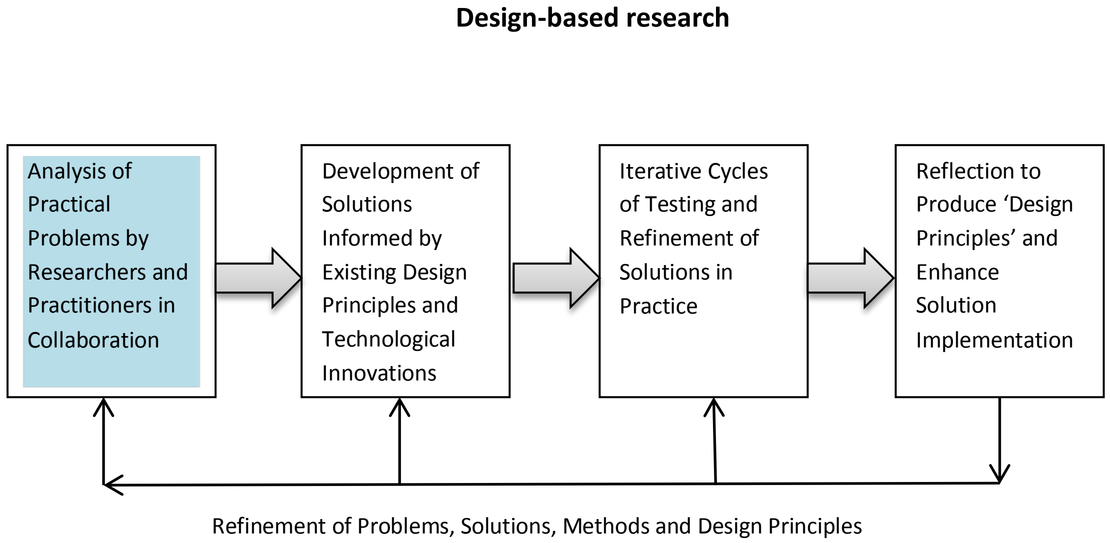
ACE	Australasian Computing Education Conference
AUT	Auckland University of Technology
AV	algorithm visualization
BRACE	Building Research in Australasian Computing Education
CER	computing education research
COS1511	Introduction to Programming I
CS Ed	Computer Science education
CUSP	course and unit of study portal
DMA	direct-manipulation animation
ET	Engagement Taxonomy
HCI	Human-Computer Interaction
ICER	International Workshop on Computing Education Research
ICO	Input, Calculate, and Output
IDE	interface development environment
ILDF	Integrative Learning Design Framework
IRT	Initialise, Repeat for each entry (in list, table, or array), and Terminate
ITiCSE	Conference on Innovation and Technology in Computer Science Education
LEM	learning edge momentum
LMS	Learning Management System
LOs	learning objects
MCQs	multiple choice questions
MOOCs	massive open online courses
ODL	open distance learning
NACCQ	Annual National Advisory Committee on Computing Qualifications
NDEEN	National Diploma in Electrical Engineering
NDINL	National Diploma: Information Technology
NDIT	National Diploma: Information Technology

PM%	the final mark for each student in the statistical analysis
PV	program visualization
SOLO	Structure of the Observed Learning Outcome
SV	software visualization
UML	Unified Modeling Language
Unisa	University of South-Africa

Note to the reader

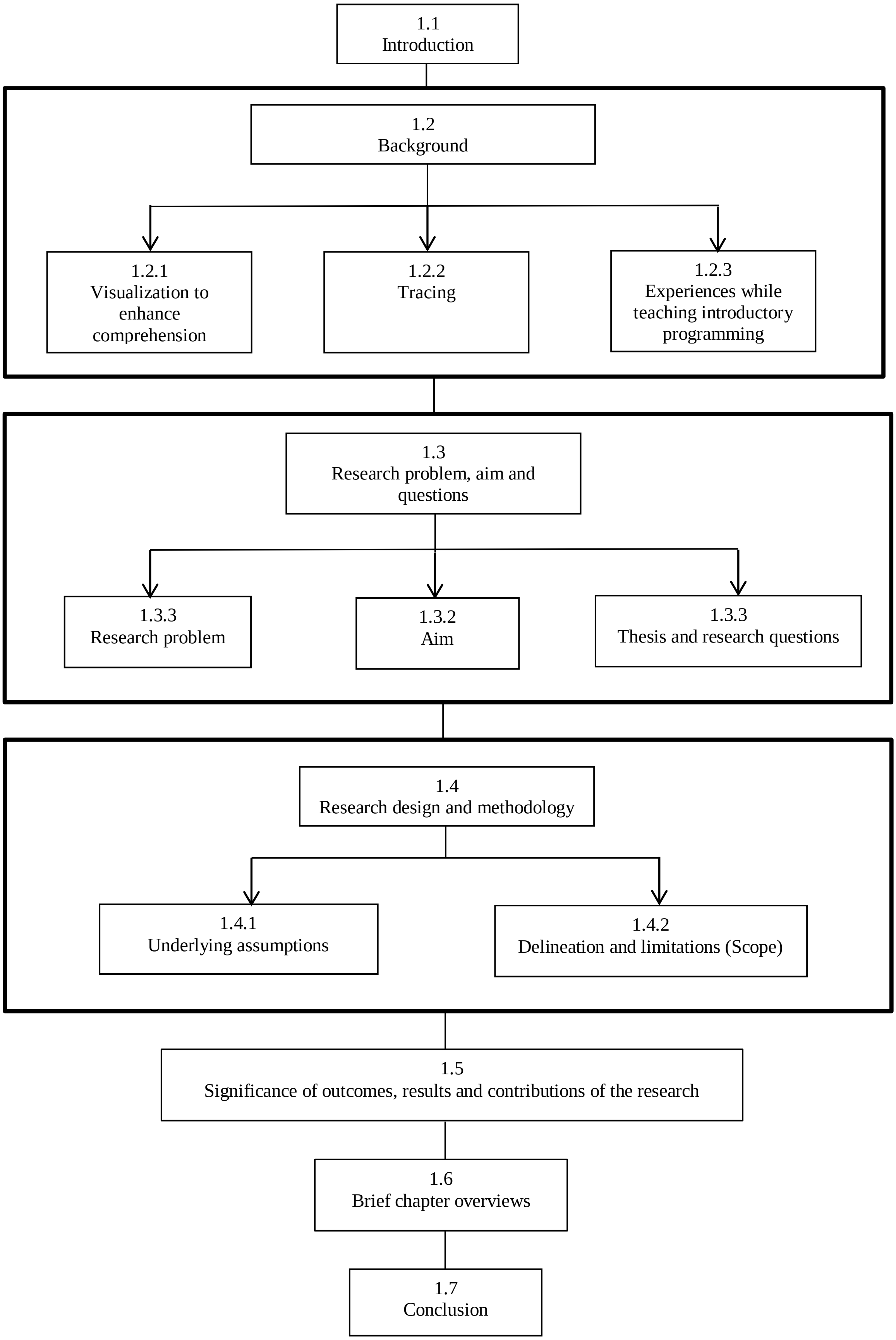
This study was conducted using design-based research. To assist the reader in understanding the process that was followed, the figure and table used on the next page, appears in front of each chapter. The figure shows the phases used in design-based while the table provides more detail on each phase and the section in the thesis where it is covered. The phase and sections covered in the chapter will be highlighted in both the figure and the table to show how the research progresses.

Design-based research phase covered in Chapter 1


Design-based research
Analysis of Practical Problems by Researchers and Practitioners in Collaboration
Development of Solutions Informed by Existing Design Principles and Technological Innovations
Iterative Cycles of Testing and Refinement of Solutions in Practice
Reflection to Produce 'Design Principles' and Enhance Solution Implementation
Refinement of Problems, Solutions, Methods and Design Principles

Phase	**Element**	**Position**
Phase of design-based research (Reeves, 2006)	*Topics/elements that need to be addressed*	*Position in this thesis*
PHASE 1: Analysis of practical problems by researchers and practitioners in collaboration	Statement of problem	Chapter 1, Section 1.3.1 Chapter 4, Section 4.3.2.1
	Consultation with researchers and practitioners	Chapter 4, Section 4.3.2.1 and section 4.3.4.3
	Research questions	Chapter 1, Section 1.3.3 Chapter 4, Section 4.3.2.3
	Literature review	Chapters 2 and 3, Section 5.2
PHASE 2: Development of solutions informed by existing design principles and technological innovations	Theoretical framework	Chapter 5, Section 5.2
	Development of draft principles to guide the design of the intervention	Chapter 5, Section 5.3
	Description of proposed intervention	Chapter 5, Section 5.5
PHASE 3: Iterative cycles of testing and refinement of solutions in practice	Implementation of intervention (First iteration) Participants Data collection Data analysis	Chapter 6
	Implementation of intervention (Second and further iterations) Participants Data collection Data analysis	Chapter 7
PHASE 4: Reflection to produce 'design principles' and enhance solution implementation	Design principles	Chapters 5, 6 and 7
	Designed artefact(s)	Available on course website
	Professional development	Chapter 8

Map of Chapter 1 (Introduction)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Chapter 1 Introduction

1.1 Introduction

This thesis describes a research project aimed at improving the tracing skills of first-year programming students enrolled for an introductory C++ course at the University of South-Africa (Unisa), to increase their comprehension and programming ability. This was done by means of a tutorial in the form of a program visualization (PV) tool to teach the students to draw variable diagrams. To develop the PV tool, the researcher first extracted a framework of guidelines/principles from the literature to guide the process. The research therefore had a twofold purpose, namely to offer a general framework of guidelines for designing and developing visualization tools to teach programming; and to put it to the test by developing a tutorial based on these guidelines, to teach introductory programing students how to draw variable diagrams to trace their programs.

In this introductory chapter, the background for the study is provided in section 1.2. Section 1.3 elaborates on the research problem, its aims and the research question. The research design and methodology are described in section 1.4, while the significance of the study's outcomes, results and contributions are discussed in section 1.5. Section 1.6 provides an overview of the chapters comprising the study, and the conclusion follows in section 1.7.

1.2 Background

It is generally accepted that it is difficult to learn how to program (Bellström & Thorén, 2009; McCracken, Almstrum, Diaz, Guzdial, Hagan, Kolikant, Laxer, Thomas, Utting & Wilusz, 2001; Pane, Ratanamahatana & Myers, 2001; Robins, Rountree & Rountree, 2003). As a result, the pass rate for students taking first-year programming courses, in general, is low, with a high drop-out rate. At the same time, there are also a high number of distinctions, thereby creating a bimodal results distribution (Bornat, Dehnadi & Simon, 2008; Corney, 2009; McCracken et al., 2001; Robins, 2010). Unisa is no exception in this regard, as the pass rate for the introductory programming module at Unisa, COS1511 (Introduction to Programming I), from 2011 to 2014 varies from 28% to 32%, while the number of distinctions at the same time varies from 8% to 14% (see Table 1.1). Being an open distance learning (ODL) institution may even exacerbate this situation, given the fact that students have to study independently, without face-to-face support.

In contrast with the above, two independent studies claim that the average pass rate for introductory programming courses worldwide is 67% (Bennedsen & Caspersen, 2007; Watson & Li, 2014), although pass rates may vary considerably – from 23.1% to 96% (Watson & Li, 2014). Nevertheless, literature shows that the teaching of programming remains a continuous field of investigation

(Morgan, Sheard, Butler, Falkner, Simon & Weerasinghe, 2015). Researchers attempt both to determine the reasons for the perceived bimodal phenomenon as well as to remedy it. This leads, to research being conducted inter alia on programming ability or aptitude; teaching and learning theories and models; teaching, learning and assessment tools and techniques; the curriculum and typical problems first-year programming students experience (Dale, 2006; Kinnunen, McCartney, Murphy & Thomas, 2007; Lahtinen, Ala-Mutka & Järvinen, 2005; Lister, Adams, Fitzgerald, Fone, Hamer, Lindholm, McCartney, Moström, Sanders, Seppälä, Simon & Thomas, 2004; Milne & Rowe, 2002; Robins et al., 2003; Sheard, Simon, Hamilton & Lonnberg, 2009; Simon, Carbone, Raadt, Lister, Hamilton & Sheard, 2008). Judging by the variety of factors investigated in this research and its results, the cause of the bimodal results distribution is probably over-determined, that is, influenced by several factors (Sheard, Simon et al. 2009).

Table 1.1 Registration, pass rate, distinctions and dropout for COS1511 from 2011 to 2014, as obtained from Unisa's Directorate Information and Analysis (DIA) (Nyalungu, 20 March 2015; Van Zyl, 15 March 2015).

Exam Year Sitting	Registration Module Count***	Examination Sitting Admitted	Normal Wrote*	Normal Pass*	Normal* Pass Rate Percentage (Passed /written %)	Number of Distinctions (Percentage of written in brackets)**	Dropout ***	Dropout rate (Dropout / Enrollment %)
2011 Jun	2381	2183	1923	549	28.5%	198 (10%)	458	19.2%
2011 Nov	1457	1197	1191	346	29.1%	111 (9%)	266	18.3%
2012 Jun	2213	2061	1827	582	31.9%	197 (11%)	386	17.4%
2012 Nov	1528	1417	1267	352	27.8%	106 (8%)	261	17.1%
2013 Jun	1180	1083	988	337	34.1%	138 (14%)	192	16.2%
2013 Nov	1145	1020	920	276	30.0%	83 (9%)	225	19.7%
2014 Jun	976	889	809	258	31.9%	101 (13%)	167	17.1%
2014 Nov	1054	1017	894	263	29.4%	78 (9%)	160	15.1%

(Legend: * – The term 'Normal' refers to students who were registered for the specific semester.
**** – The percentage of students who wrote the examination and obtained distinctions appears in brackets after the number of distinctions.**
***** – 'Dropout' refers to students who were registered at the end of the semester but did not write the examination. It does not include cancellations, which will raise the dropout rate considerably when taken into account.) Similarly, 'Registration Module Count' indicates the number of students still registered by the end of the semester and therefore excludes cancellations.**

In an attempt to explain this phenomenon, Robins (2010:58) suggests a new mechanism, referred to as learning edge momentum (LEM). The learning edge is "the boundaries of existing knowledge which form the context into which newly learned concepts (information, understanding and skills) must be integrated". Over time, the consequences of either successful or unsuccessful learning becomes self-reinforcing, since any successful learning in a specific domain makes it easier to some extent, to acquire further related concepts from that domain, while unsuccessful learning has the opposite effect. Robins (2010) also investigated the well-known assumption that there are two different groups of people, those who can program and those who cannot. He found no convincing evidence to support this premise, and therefore proposes that both the high drop-out and bi-modal results distribution in introductory computer science courses, are due to the nature of the subject material concerned. To improve the pass rate and lower the drop-out rate, effective teaching and learning during the initial stages of first-year programming courses, should take advantage of the LEM mechanism to achieve a better through-put rate (Robins, 2010).

Two aspects employed to improve the success of novice programmers, both related to this study, namely visualization and tracing, are discussed below as well as the researcher's experiences while teaching introductory programming.

1.2.1 Visualization to enhance comprehension

Visualization is one of the methods used by computer science educators to assist students in mastering programming concepts. Software visualization (SV) in particular, aims to demonstrate different elements of software graphically, so that users can comprehend and reason about it (Petre & Quincey, 2006). This may take on the form of either AV or PV. AV demonstrates the high-level operations of an algorithm to assist understanding of its procedural behaviour (Hundhausen, Douglas & Stasko, 2002). PV shows the effect of each operation in implemented code (Röβling, Malmi, Clancy, Joy, Kerren, Korhonen, Moreno, Naps, Oechsle, Radenski, Ross & Velazquez-Iturbide, 2008). PV also facilitates program comprehension and debugging (Helminen & Malmi, 2010).

The success of SV is debatable. It is for instance, not always pedagogically successful (Foutsitzis & Demetriadis, 2008; Hundhausen et al., 2002; Lahtinen, 2008; Naps, Röβling, Almstrum, Dann, Fleischer, Hundhausen, Korhonen, Malmi, McNally, Rodger & Velázquez-Iturbide, 2003; Pears, Seidman, Malmi, Mannila, Adams, Bennedsen, Devlin & Paterson, 2007; Shaffer, Cooper & Edwards, 2007). Responses about the situations in which PVs are useful are also ambiguous – students may use PVs while studying, but claim they are most beneficial when presented by a teacher (Lahtinen, Jarvinen & Melakoski-Vistbacka, 2007). On the other hand, the literature indicates that individual engagement is essential to benefit from visualization (Isohanni & Knobelsdorf, 2011; Kaila, Rajala, Laakso & Salakoski, 2009). Depending on the level of engagement with visualization, it can improve knowledge acquisition, attitude and programming skills (Urquiza-Fuentes & Velázquez-Iturbide, 2009a).

A significant number of SVs have been developed, but they are rarely used by teachers or lecturers other than the developers themselves. While instructors may agree that visualizations can help students, they are frequently not sufficiently convinced of its value to use it. They cite reasons for not using it, such as the difficulty and lack of time to adapt and maintain the visualization according to the courseware used at the institution (Ben-Bassat Levy & Ben-Ari, 2007; Domingue, 2002; Hundhausen & Brown, 2007; Naps, Röβling et al., 2003; Pears, East, McCartney, Ratcliffe, Stamouli, Berglund, Kinnunen, Moström, Schulte & Eckerdal, 2007; Röβling et al., 2008). According to Shaffer, Cooper, Alon, Akbar, Stewart, Ponce and Edwards (2010:9:18), "much of AV development seems to occur in a social vacuum", since despite larger developers communicating with each other, smaller developers do not seem to be aware of the results of studies on the effectiveness of visualizations.

1.2.2 Tracing

Research has shown that students need to be able to read (that is trace) and explain code to be capable to write code (Lister, Clear, Simon, Bouvier, Carter, Eckerdal, Jacková, Lopez, McCartney, Robbins, Seppälä & Thompson, 2010; Lopez, Whalley, Robbins & Lister, 2008; Philpott, Robbins & Whalley, 2007; Rountree, Rountree, Robins & Hannah, 2005; Sheard, Carbone, Lister, Simon, Thompson & Whalley, 2008; Venables, Tan & Lister, 2009). Soloway (1986:857) pointed out this requirement in 1986 already, by stating that "designers and maintainers who did not carry out simulations did not develop an effective design or an effective enhancement".

The BRACElet project's[1] research (Clear, Philpott & Robbins, 2009; Lister et al., 2004; Lister et al., 2010; Whalley & Lister, 2009) suggests that novice programmers develop these skills in a hierarchical order, as follows: They first learn to read, that is trace, code. Once this ability becomes dependable, they develop the skill to explain code. When students are reasonably adept at both reading and explaining, the capacity to systematically write code develops. The skills in this hierarchy are not necessarily acquired in a strict order, but instead support each other and improve in parallel. However, a certain minimal competency at tracing and explaining is required, before a minimal competence to systematically write code is displayed (Lister et al., 2010; Lister, Fidge & Teague, 2009; Venables et al., 2009; Whalley & Lister, 2009).

Cogan and Gurwitz (2009) indicated that teaching students memory tracing (tracking the changes in values of all variables on paper during program execution) early in their introductory programming courses, improved the pass rate rate. Hertz and Jump (2013) report similar results. This seems to

[1] The BRACElet project was a multi-institutional multi-national study investigating novice acquisition of programming skills. In Chapter 3 the BRACElet project is discussed in detail.

confirm both BRACElet's findings (Lister et al., 2009; Venables et al., 2009) and the LEM effect (Robins, 2010).

Calls for teaching students manual memory tracing (Lister, 2007; Lister et al., 2004; Lister et al., 2009; Soloway, 1986) are supported by the benefits of doing so. Manual memory tracing teaches students to focus on understanding the detail of what their programs actually do (Cogan & Gurwitz, 2009; Lister et al., 2004; Lister et al., 2009; McCracken et al., 2001; Perkins, Hancock, Hobbs, Martin & Simmons, 1989). This allows them to create a mental model of the program and to predict its behaviour (Robins et al., 2003), which in turn assists in avoiding errors and finding them more quickly (Cogan & Gurwitz, 2009). It also serves a motivational role by breaking down the initial technical and emotional barriers to the complicated process of creating correct code, while better preparing them to understand more difficult algorithms (Cogan & Gurwitz, 2009). This encourages them to continue doing so (Thomas, Ratcliffe & Thomasson, 2004).

In the light of the above, it is clear that in an ODL environment such as Unisa, where students usually have to study without physical contact with lecturers or fellow students, the ability to trace in order to analyze and debug programs, therefore is all the more important. Furthermore, manual tracing is an important debugging skill. Therefore this is important in writing code too, especially when maintaining programs written by others.

1.2.3 Experiences while teaching introductory programming

In the introductory programming course at Unisa, COS1511, memory tracing is taught by means of static variable diagrams. While explaining these static variable diagrams to students during individual consultations, the researcher noticed that they seemed to understand a manual visual simulation of tracing, that is what happens in computer memory while a program is being executed, much better. In marking examination scripts for the follow-up first-year module, she also noticed that the kind of errors students make can be linked to lack of knowledge and comprehension of the processes that occur in CPU memory during program execution, particularly during parameter transfer. This corresponds to the findings of Milne and Rowe (2002), who ascribe students' problems with object-oriented programming to lack of a clear mental model of how their programs' storage work in memory and how objects in memory relate to each other.

The findings by the BRACElet project (Clear et al., 2009; Lister et al., 2004; Lister et al., 2009; Whalley & Lister, 2009) triggered the researcher's interest in providing a way to assist introductory programming students at Unisa in learning to trace, in the hope that this would assist them to master the art of programming. Since PV has been used successfully in non-ODL settings, the researcher wished to provide Unisa's introductory programming students with a tool to compensate for their lack of face-to-face instruction. The tool took the form of a customized tutorial to teach students to draw variable diagrams to do memory tracing. The tutorial was *not* intended as a tool to be used during program construction, but instead to teach the students how to do manual tracing. This is in line with research showing that students need to engage with tracing themselves, in order to benefit from it (Hundhausen et al., 2002; Lauer, 2008; Naps, Röβling et al., 2003; Thomas et al., 2004).

1.3 Research problem, aim and questions

Against this background, the research problem addressed in this study, its aim, thesis and the research questions are described below.

1.3.1 Research problem

The research problem addressed in this study was formulated as follows:

As can be seen in Table 1.1, the pass rate for the introductory first-year programming course at Unisa (COS1511) is consistently low, varying between 28% and 32% from 2011 to 2014. At the same time the dropout rate varies between 15% and 20% with the number of distinctions from 8% to 14%.

The low pass rate and high drop-out in the first introductory programming course at Unisa (COS1511), is exacerbated by the demands of the ODL environment, where students have to study on their own, without face-to-face contact with lecturers. The diverse backgrounds of Unisa's students and the wide variety of degrees for which COS1511 students are enrolled, pose additional challenges, such as varying levels of computer literacy, English being the second or third language for the majority of students and classes consisting of large numbers of students (Schoeman, Gelderblom & Muller, 2013). In particular, the problem seems to be the fact that students experience problems to understand and learn from text-based study material how to draw variable diagrams to trace program code.

1.3.2 Aim

Since PV has achieved a measure of success in non-ODL environments, as mentioned above, the effect of a PV tool (a tutorial) to enhance comprehension of tracing in ODL computer programming education with the aim of improving the pass rate of first-year programming students at Unisa, was investigated. To this end, the researcher examined guidelines from literature for using visualization to teach programming and developed a framework to guide the design of PV tools for teaching programing. Based on these guidelines, a PV tool in the form of a customised tutorial to teach students to draw variable diagrams to do memory tracing, was developed and put to the test. The aim of the tutorial was to teach students to draw variable diagrams to track the run-time behaviour of programs themselves.

This research therefore had a twofold aim:

- to create a framework of guidelines for designing, developing and using visualization tools to teach programming; as well as
- to test the framework to determine whether a PV tool to teach tracing based on the framework of guidelines enhances comprehension in such a manner that it assists students in an ODL environment in mastering the art of programming to the extent that it impacts the pass rate for the module.

1.3.3 Thesis and research questions

In the light of the research problem and the aim of this research, the thesis of this PhD is:

A framework of guidelines for using and creating visualization tools to teach programming, synthesized from literature and tested and refined through practical application, can be employed to develop a PV tool to teach introductory programming students in an ODL environment, to trace programs in order to improve students' programming skills.

To test this thesis the researcher investigated the following research questions:

1. What guidelines and principles for using and creating visualizations to teach programming, can be derived from literature?
2. Will a tutorial to teach tracing to visualize program execution and parameter transfer, based on the framework of guidelines, assist students in acquiring programming skills in an ODL environment so that it is noticeable in average marks?
3. How do students' biographical properties, their positive user experience, their use of tracing and the extent and manner of tutorial use, affect their ability to acquire programming skills in an ODL environment?
4. What lessons have been learnt through the practical testing and refinement of the visualization tool?

1.4. Research design and methodology

The research design and methodology for this research is described in detail in Chapter 4. Therefore only a brief overview of the design and methodology is given here.

The research design for this study was based on design-based research, the educational variation of design research. This variation is frequently used in computing education research (CER) to do research in naturalistic settings (Cooper, Grover, Guzdial & Simon, 2014). Design-based research consists of an iterative analysis, design, development and implementation process that delivers both a practical and theoretical contribution. The practical contribution is based on using existing technology to develop an intervention to solve a real-world problem. During this process a theoretical contribution is generated by enhancing existing design theories and principles. Accordingly, in applying the research design for this research, the researcher followed a pragmatic approach that aimed to solve a real-world problem, as discussed in section 1.3.1, and focused on usefulness. The two contributions constituting the aims of the research are indicated in section 1.3.2.

No comprehensive research methodology for design-based research has yet been identified or accepted (Mingfong, Yam San & Ek Ming, 2010; Morgan, 2013; Oh & Reeves, 2010; Plomp & Nieveen, 2009). The methodology followed in this study is based on Reeves' (2006) four phases of design-based research consisting of the –

- analysis of practical problems in collaboration with practitioners;
- development of solutions informed by existing design principles and technological innovations;
- iterative cycles of testing and refinement of solutions in practice; and
- reflection to produce design principles and enhance solution implementation.

As applied in this research, the first phase included the statement of the problem; a discussion of consultation with researchers and practitioners; and the research questions as well as the literature review. During phase 2 the theoretical framework, the development of draft principles to guide the design of the intervention and a description of the proposed intervention was developed. In phase 3, two iterative cycles of implementation of the intervention, including the participants, data collection and analysis were described. Phase 4 presents the design principles, and the designed artifact as well as a reflection on the professional development of the researcher. The chapter overviews in section 1.6 relate each of Reeves' (2006) four phases of design-based research to specific chapters. This provides more detail on the research process followed.

The underlying assumptions and scope of the research design and methodology are described below.

1.4.1 Underlying assumptions

The underlying assumption was made that the composition of the student cohort registered for COS1511, would not change significantly during the time the study was conducted.

It was assumed that Robins' (2010) LEM effect is valid, and no attempt to prove or disprove it, was made.

1.4.2 Delineation and limitations (Scope)

This study built on the work done by the BRACElet team (Clear et al., 2009; Lister et al., 2004; Lister et al., 2009; Whalley & Lister, 2009).

The study was conducted on only one first-year programming module, namely COS1511.

The Drawing Variable Diagrams Tutorial was not intended as a tool to be used during program construction, but instead to teach the students how to do manual tracing of variables. It only demonstrated selected examples from the COS1511 Study Guide to teach students how to draw variable diagrams for the programming constructs covered in the COS1511 syllabus.

The investigation into the factors that influence marks of students who have access to the tutorial in COS1511, was limited to their biographical properties, their positive user experience, their use of tracing and the extent and manner of their tutorial use. Questionnaires to investigate these factors were distributed to all the COS1511 students in the quantitative investigation. This resulted in self-selection sampling, a nonprobability sampling method, which could have been biased towards students willing to answer the questionnaires (Fowler Jr, 2009; Oates, 2006). The number of responses on the questionnaires has been a limitation. Since the qualitative investigation also used self-selection sampling, the same bias regarding willing participants could have applied.

1.5 Significance of outcomes, results and contributions of the research

The theoretical contribution of this PhD lies in the guidelines provided in the framework for designing, developing and using visualization tools to teach programming that was developed. A considerable number of the guidelines in the framework are supported by reasons or explanations, and/or considerations that should be taken into account when applying the guideline, since some guidelines contra-indicate others. Although various studies have presented guidelines for creating visualizations, a comprehensive framework of this nature for designing, developing and using visualization tools, could not be identified by this researcher. The results of this research therefore make a unique contribution to the guidelines for creating visualizations to teach programming.

It is envisaged that these guidelines would be used to develop PV tools and may serve as a departure point for the construction of a generic PV system for introductory programming that could possibly allow integration with other course materials, as advocated by Sorva, Karavirta and Malmi (2013). Introductory programming instructors could also use it to evaluate existing PV tools to determine whether it would be suitable for the intended purpose, and how to use it. This addresses the need for models for teaching and learning of programming, as expressed in the literature (Cooper et al., 2014; Sheard et al., 2009). Its application could therefore improve the teaching of computer programming.

According to Sorva, Karavirta and Malmi (2013:15:54) “Evaluative studies on interventions in which PV is strongly and longitudinally integrated into a CS1 courses are scarce”. Accordingly, they recommend the undertaking of more empirical research to allow informed decisions about the use of PV tools to be taken (Sorva, Karavirta & Malmi 2013). This research is such a study and the intention with it is to contribute to the understanding of how novice programmers develop proficiency (Lister et al., 2010). As can be seen from Table 1.1, this study was conducted on classes consisting of large numbers of students, with regular enrollments of a minimum of 1000 students per semester. This lends credibility to the results of the study.

Improving the teaching of computer programming, supports the South African Department of Higher Education and Training's Strategic Plan 2010-2015 (Strategic Planning 2010-2015, 2010) that calls for an improvement of teaching and learning practices and applying the lessons learnt in best practices across the system. This corresponds to a worldwide trend for empirical research to evaluate and disseminate new teaching initiatives (Morgan et al., 2015; Sheard, Morgan, Butler, Falkner, Weerasinghe & Cook, 2014; Sorva, Karavirta & Malmi, 2013).

In practical real life, this study can assist students to master the skill of tracing and as a result, the art of programming. Students who have laid a good foundation in the art of programming in the first introductory module should –

- enjoy a solid base for further modules and enhanced comprehension in follow-up modules; and
- complete their degrees in a shorter time, and at a lower cost.

In general, successfully enhancing students' programming skills will –

- improve the pass rate, which is typically very low, for COS1511 first-year programming students in Unisa's ODL environment;
- relieve the pressure on lecturers from students who repeat the same module several times;
- increase the subsidy Unisa receives from government; and
- relieve the shortage of skilled IT workers in South-Africa.

In turn, these practical real life benefits will improve the graduation rate at Unisa and the rate at which key skills necessary for economic growth and social development are delivered, in line with the strategic priorities of the RSA's Department of Higher Education and Training's Strategic Plan 2010-2015 (Strategic Planning 2010-2015, 2010).

Teaching and assessing students on manual tracing, also supports the ACM's appeal for an emphasis on the teaching of basic programming, in order to answer industry's need for quality in terms of testing, debugging and bug tracking, as well as its need for code archeology (that is making sense of large, poorly-documented code bases) (Cassel, Clements, Davies, Guzdial, McCauley, McGettrick, Sloan, Snyder, Tymann & Weide, 2008).

1.6 Brief chapter overviews

The literature review runs over two chapters, Chapters 2 and 3. Both are part of phase 1 in the design–based research methodology used in this study. Chapter 2 provides the context and theoretical base for the research by discussing open-distance learning (ODL), e-learning, massive open online courses

(MOOCs), teaching programming in distance education, teaching introductory programming courses and the role of tracing and visualization in teaching programming. Chapter 3 analyses the contribution of the BRACElet project to teaching programming. The motivation for the BRACElet study, the study itself, its findings, follow-up work and its implications are covered.

In Chapter 4 the research design and methodology for this study are discussed. This is also part of phase 1 in the design-based methodology used in this research. Firstly, the structure of a research design in general is described and then the research design for this study is explicated. This includes a discussion of the nature of design-based research, its challenges and advantages and ensuring validity during design-based research. The research problem for this PhD study is then discussed in detail and the philosophical approach followed is justified. The context of the research is sketched and the four phases in the methodology are described, as well as validating the research effort and the ethical considerations.

Chapter 5 describes the development of the tutorial to draw variable diagrams. This covers the last part of phase 1 as well as phase 2 of this design-based research effort. The first part of the chapter consists of a literature study of guidelines from three areas for using and creating visualization tools, namely CER, educational psychology and computer graphics. A framework of guidelines for using and creating visualization tools is then developed, based on guidelines from the literature. In the second part of the chapter, a description of the tutorial to draw variable diagrams; the motivation for design decisions taken in its development; the development process itself; and the initial testing are described. Lessons learnt during the development and initial testing, as well as further guidelines are described. Chapter 5 therefore answers the first research question:

> What guidelines and principles for using and creating visualizations to teach programming can be derived from literature?

It also partially answers the fourth research question:

> What lessons have been learnt through the practical testing and refinement of the visualization tool?

Chapters 6 and 7 describe the findings of this study with regard to the practical implications of the study, that is, the effect that using the tutorial has on students' performance. It covers the first and second cycles of implementation of the intervention, namely phase 3 in this design-based research. Chapter 6 and 7 therefore answer the second and third research questions, as well as the fourth research question namely:

2 Will a tutorial to teach tracing to visualize program execution and parameter transfer, based on the framework of guidelines, assist students in acquiring programming skills in an ODL environment so that it is noticeable in pass rates or average mark?

3 How do students' biographical properties, their positive user experience, their use of tracing and the extent and manner of tutorial use, affect their ability to acquire programming skills in an ODL environment?

4. What lessons have been learnt through the practical testing and refinement of the visualization tool?

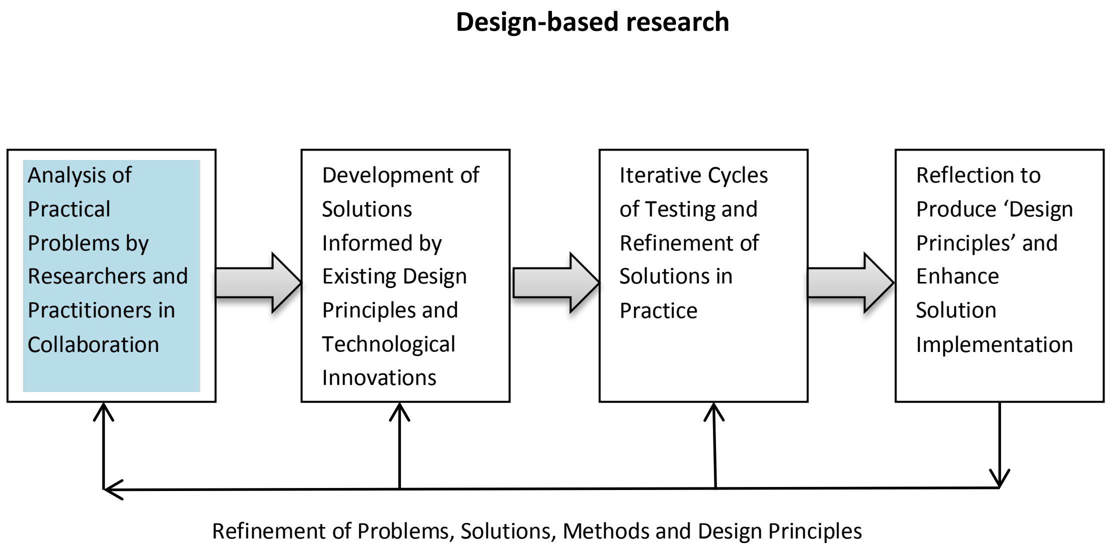
Chapters 6 and 7 follow a similar structure. The participants and data collection and analysis are described. The data collection and analysis comprised two parts, a quantitative and a qualitative investigation. A summary of the findings and an evaluation thereof were used then to adapt the tutorial. The findings were also used to adapt the questionnaire employed in the first cycle for the second cycle. In both chapters the findings also offer some lessons learnt during the practical testing and refinement of the tutorial.

Finally, Chapter 8 provides the summary and conclusion.

1.7 Conclusion

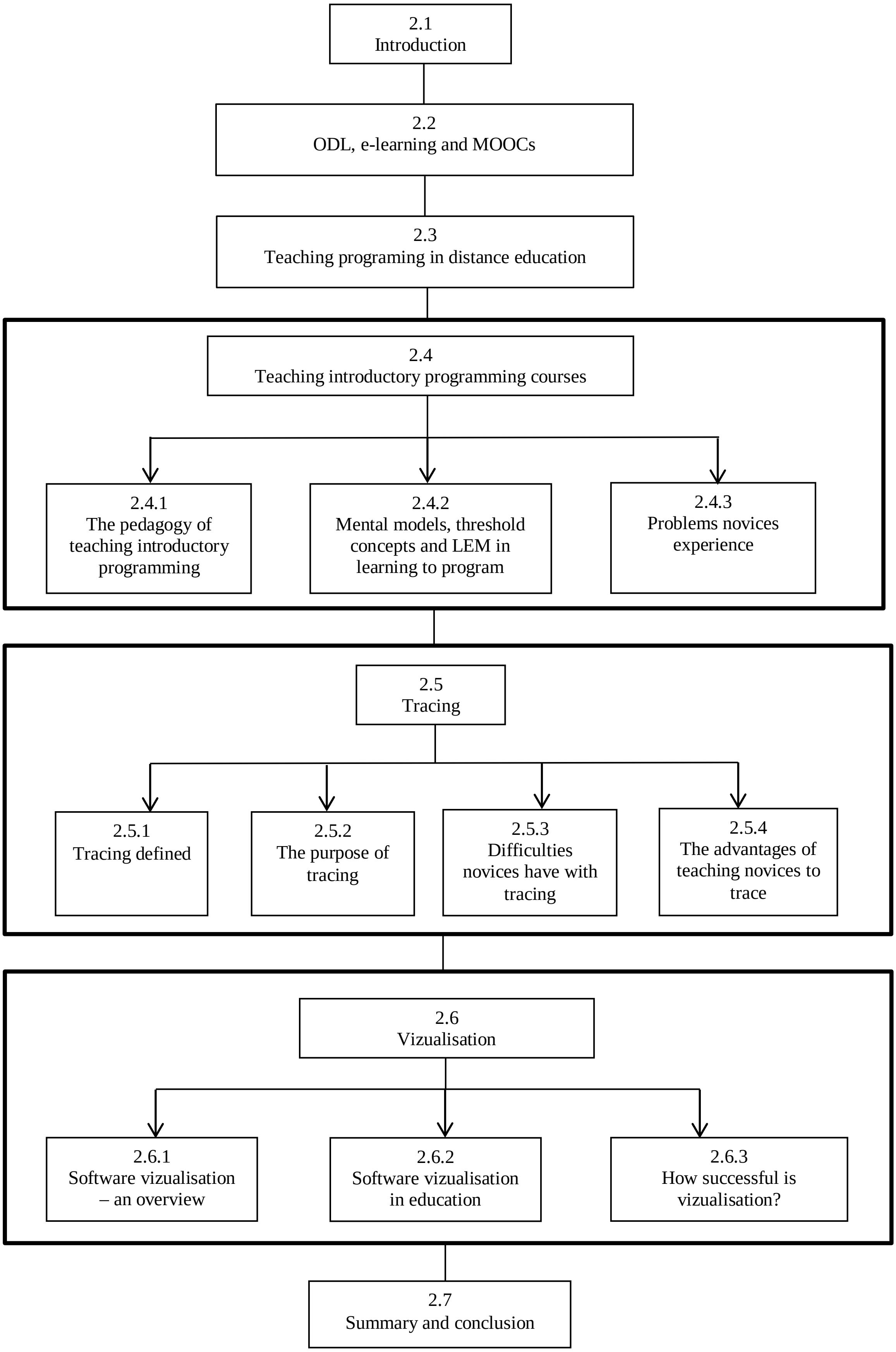
This thesis reports on a study to improve introductory programming students' tracing skills in an ODL environment. The researcher's contribution is twofold, namely presenting a framework of guidelines for designing and developing visualization tools to teach programming that can be used both to develop new tools and to evaluate existing tools for possible use; as well as the results of an empirical investigation in using the framework to develop and test a tool to teach introductory programming students to trace.

Design-based research phase covered in Chapter 2


Design-based research
Analysis of Practical Problems by Researchers and Practitioners in Collaboration
Development of Solutions Informed by Existing Design Principles and Technological Innovations
Iterative Cycles of Testing and Refinement of Solutions in Practice
Reflection to Produce 'Design Principles' and Enhance Solution Implementation
Refinement of Problems, Solutions, Methods and Design Principles

Phase	**Element**	**Position**
Phase of design-based research (Reeves, 2006)	*Topics/elements that need to be addressed*	*Position in this thesis*
PHASE 1: Analysis of practical problems by researchers and practitioners in collaboration	Statement of problem	Chapter 1, Section 1.3.1 Chapter 4, Section 4.3.2.1
	Consultation with researchers and practitioners	Chapter 4, Section 4.3.2.1 and section 4.3.4.3
	Research questions	Chapter 1, Section 1.3.3 Chapter 4, Section 4.3.2.3
	Literature review	Chapters 2 and 3, Section 5.2
PHASE 2: Development of solutions informed by existing design principles and technological innovations	Theoretical framework	Chapter 5, Section 5.2
	Development of draft principles to guide the design of the intervention	Chapter 5, Section 5.3
	Description of proposed intervention	Chapter 5, Section 5.5
PHASE 3: Iterative cycles of testing and refinement of solutions in practice	Implementation of intervention (First iteration) Participants Data collection Data analysis	Chapter 6
	Implementation of intervention (Second and further iterations) Participants Data collection Data analysis	Chapter 7
PHASE 4: Reflection to produce 'design principles' and enhance solution implementation	Design principles	Chapters 5, 6 and 7
	Designed artefact(s)	Available on course website
	Professional development	Chapter 8

Map of Chapter 2 (Literature review)


2.1
Introduction
2.2
ODL, e-learning and MOOCs
2.3
Teaching programing in distance education
2.4
Teaching introductory programming courses
2.4.1
The pedagogy of teaching introductory programming
2.4.2
Mental models, threshold concepts and LEM in learning to program
2.4.3
Problems novices experience
2.5
Tracing
2.5.1
Tracing defined
2.5.2
The purpose of tracing
2.5.3
Difficulties novices have with tracing
2.5.4
The advantages of teaching novices to trace
2.6
Vizualisation
2.6.1
Software vizualisation – an overview
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Software vizualisation in education
2.6.3
How successful is vizualisation?
2.7
Summary and conclusion

Chapter 2 Literature review

2.1 Introduction

This research investigated the effect of introducing a tutorial to teach tracing, into the course material of an introductory programming course at Unisa, a large open distance learning (ODL) institution. The tutorial resembles a PV tool that shows the internal computer memory during a step by step execution of a program, similar to tracing a program. This chapter provides the context and theoretical base for the research. To this end, the following topics are addressed here: ODL, e-learning and MOOCs; teaching programming in distance education; teaching introductory programming courses; tracing; and visualization. This study is based on research by the BRACElet project (Clear, Whalley, Robbins, Philpott, Eckerdal, Laakso & Lister, 2011) that contributed substantially to the body of work on teaching introductory programming, between 2004 and 2010. In their work the role of tracing in learning to program, is of particular importance for this research. The contribution of the BRACElet project will be covered in Chapter 3.

Section 2.2 defines the ODL environment at Unisa, where this research was done. The teaching of programming in distance education in general is discussed in section 2.3, while section 2.4 focuses on teaching introductory programming courses. This section covers the pedagogy of teaching introductory programming, and elaborates on mental models, threshold concepts and the learning edge momentum (LEM) effect in learning to program. Also considered is the problems novices experience, by referring to the differences between novices and experts and investigating the concepts novices find difficult.

Tracing is one of the ways that can be used to address misconceptions novices have and to assist them in developing mental models for programming (Robins et al., 2003). Section 2.5 focuses on research findings regarding the use of tracing to teach programming, and addresses the role of tracing in programming, difficulties novices have with tracing and the advantages of teaching novices to trace. The tutorial that was developed for this study uses a form of software visualization, namely PV to teach tracing. Section 2.6 presents the background on visualization. It provides an overview of SV in general, and in particular of SV in education. The success of visualization in education is investigated. Section 2.7 concludes the chapter.

Figure 2.1 shows the relationships between these topics and their contribution to the background for the development of the tutorial. As depicted by Figure 2.1 the ODL environment in which the course is offered; the teaching of programming in distance education, and in particular teaching introductory programming by means of visualization, the findings of the BRACElet project (Clear et al., 2011) and the importance of tracing were all factors that played a role in the development and implementation of the tutorial.

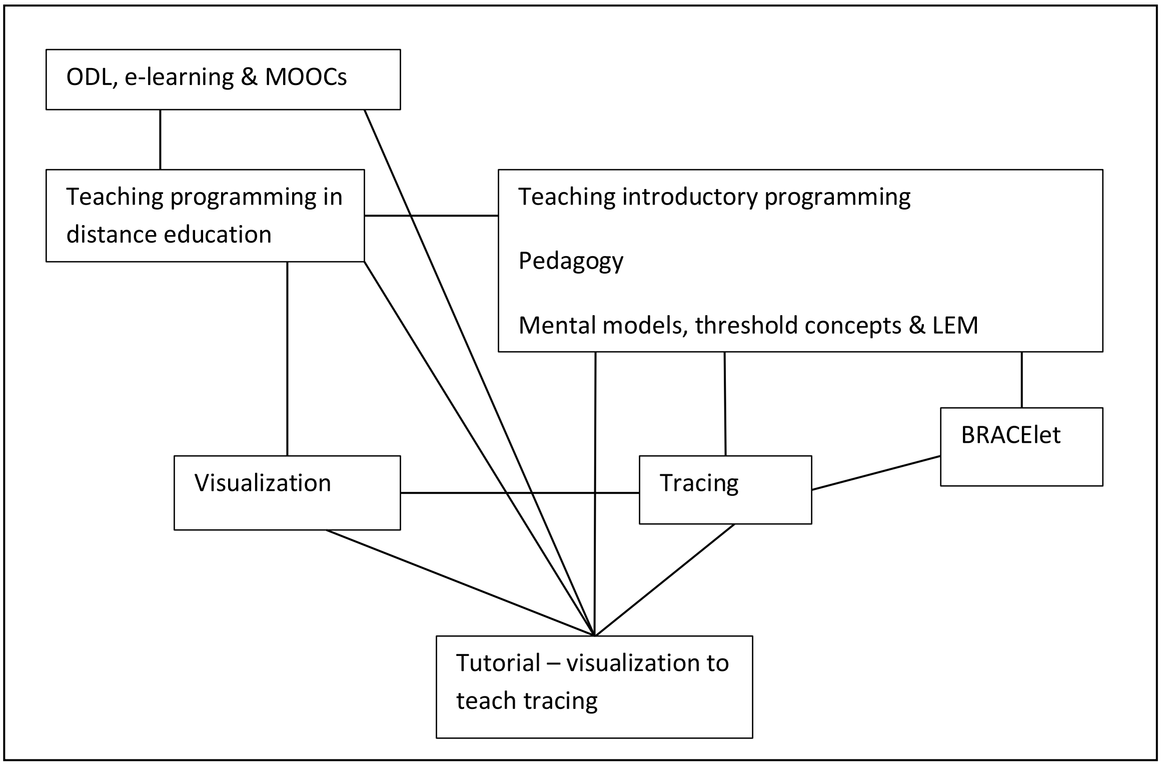

ODL, e-learning & MOOCs
Teaching programming in distance education
Teaching introductory programming
Pedagogy
Mental models, threshold concepts & LEM
BRACElet
Visualization
Tracing
Tutorial – visualization to teach tracing

Figure 2.1 Relationship between literature review topics

2.2 ODL, e-learning and MOOCs

The University of South Africa (Unisa) is the only comprehensive dedicated distance education university in South-Africa and applies what is known as an ODL policy (UNISA Open Distance Learning Policy, 2008). Distance education is characterised by the physical separation between the learning institution and its students. However, the 'distance' also includes time, economic, social, educational, epistemological and communication distances between not only the institution and its students, but between students themselves too (Heydenrich & Prinsloo, 2010). In addition, for students who have to study on their own, inadequate listening skills (Roberts & Gous, 2014) or reading skills (Gous & Roberts, 2014) may add to the 'distance'. Open learning refers to an approach where the institution allows students to have flexibility and choice in what, when, where, at what pace and how they learn (Jeffries, Lewis, Meed & Merritt, 1990; UNISA Open Distance Learning Policy, 2008).

Although most international literature uses the term 'open and distance learning', Unisa employs the term 'open distance learning' as indicated above (Heydenrich & Prinsloo, 2010; UNISA Open Distance Learning Policy, 2008). According to UNESCO, open and distance learning "stresses at the same time openness concerning access, organization and methods, flexibility in delivery and communication patterns, and the use of various technologies in support of learning" (Unesco Open and Distance Learning: Prospects and Policy Considerations, 1997:10). Unisa combines the characteristics of distance education and the approach of open learning into ODL. The University therefore defines it as “a multi-dimensional concept aimed at bridging the time, geographical, economic, social, educational and communication distance between student and institution, student and academics, student and courseware and student and peers” (UNISA Open Distance Learning Policy, 2008:2). It also focuses on “removing barriers to access learning, flexibility of learning provision, student-centeredness, supporting students and constructing learning programmes with the expectation that students can succeed” (UNISA Open Distance Learning Policy, 2008:2).

Unisa follows the fifth generation model in distance education (Moore & Kearsley, 2011; Taylor, 2001) with open, distance and e-learning (ODeL) tuition. ODeL aims to provide all teaching and learning material to students in digital format. Once this has been phased in completely, all students will have access to an eTutor or eMentor and core student assessment, except undergraduate examinations and practical assignments, will be managed electronically and online. This places significant emphasis on e-learning in the Unisa environment as a means to bridge the distance in ODL.

Although e-learning typically refers to using the Internet for instruction and learning (Neal & Miller, 2005) some definitions include all electronic media such as Web-based learning, computer-assisted instruction, multi-media CD-ROMs, online course and audio/video tape as well as the Internet and intranets (De Villiers, Becker & Adebesin, 2012; Hung, 2012). According to Masie (2009), e-learning has evolved from the electronic design, delivery and administration of learning to using search tools, social learning activities, YouTube-like video segments and expanded blended learning. Currently Masie’s definition (2009) as well as the broader definition of e-learning as used by De Villiers et al. (2012) and Hung (2012) are applied to various degrees in different faculties in the Unisa environment. Printed material, audio- and videoconferencing, discussion classes, face-to-face tutors or e-tutors are also used.

A relatively new development in distance education is MOOCs offered by private online learning companies and universities such as Stanford, MIT and Harvard. Well-known entities offering MOOCs are Coursera (see http://www.coursera.org), the Khan Academy (see http://khanacademy.org), Udacity (see https://www.udacity.com) and edX (see http:://www.edx.org). MOOCs typically have no entry-level requirements; and offer enrolment, quizzes, assignments, statements of accomplishment and so forth, but do not offer academic credit or charge tuition fees, although some may provide certification at a cost (Cooper & Sahami, 2013; Daniel, 2012; Martin, 2012). A number of MOOCs now offer proctored examinations which may be used to apply for certification for transfer credit through the American Council on Education (Lewin, 2013). Some residential universities incorporate MOOCs in traditional courses with students watching online course videos before discussing it during class time (Lewin, 2013; Martin, 2012).

Technological developments and infrastructure allow conventional universities to integrate and adopt open and distance learning with blended or hybrid forms of delivery, teaching, learning and support. For example, learning management systems (LMSs) such as WebCT, Blackboard, Moodle and Sakai are used to manage and support both distance education and residential education. This reduces the distinction between residential and distance education (Heydenrich & Prinsloo, 2010; Unesco Open and Distance Learning: Prospects and Policy Considerations, 1997).

Unisa's vision is to become "*the* African university in service of humanity" (UNISA Open Distance Learning Policy, 2008:1). In 2012 and 2013, during the implementation phase of this PhD study, Unisa had more than 400 000 students from across South-Africa, Africa and other parts of the world (Unisa at a Glance 2012, 2012; Unisa at a Glance 2013, 2013). Of these, in 2012, 69% were African, and 4.8% came from outside South-Africa (Unisa at a Glance 2012, 2012). In 2013, 68% were African and 9% came from beyond the borders of South-Africa (Unisa at a Glance 2013, 2013). The language of tuition is English, which means Unisa has a large number of students who study in their second or third language. Furthermore, students at Unisa come from both urban and rural areas where the infrastructures are vastly different. The level of exposure to and availability of modern technology also affects the level of technical support that can be given by the learner support system in these areas (Sonnekus, Louw & Wilson, 2006). Mbatha and Naidoo (2010) found that even in an urban area (Pretoria), students do not actively engage in e-learning. They use Unisa's LMS, myUnisa, only for basic educational needs and not to engage with other learners and stakeholders. In South-Africa, more and more school leavers are entering distance education (Heydenrich & Prinsloo, 2010). In both 2012 and 2013, 26% of students enrolled at Unisa were 24 years or younger (Unisa at a Glance 2012, 2012; Unisa at a Glance 2013, 2013). Many of these students are underprepared by the school system and struggle to adapt to higher education (Heydenrich & Prinsloo, 2010; Scott, Yeld & Hendry, 2007). A number of researchers have indicated that students at SA tertiary institutions, and in particular those for whom English is their second language, suffer from poor reading skills (Gous and Roberts, 2014; Matjila and Pretorius, 2004; Pretorius and Ribbens, 2005). Poor reading skills could increase the level of distance in ODL as Unisa research shows that the average first-year student, from a background where reading was neglected, could have the reading ability of twelve-year olds, not eighteen-year olds (Kilfoil, 2008). Therefore, despite all the technological advances, the various 'distances' in ODL remains a factor that influences the learning experience of students at Unisa, and may well have an effect on their performance. This should be taken into account when designing study material.

2.3 Teaching programming in distance education

As mentioned before, LMSs allow conventional universities to offer both residential and distance education. As a result, apart from the face-to-face contact, there is little difference between teaching programming face to face and teaching it online. Frequently, a course is offered both face to face and online with the same model followed for both courses (Bruce-Lockhart & Norvell, 2007b; Chinn, Sheard, Carbone & Laakso, 2010; de Raadt, Watson & Toleman, 2009; MacDonald, Dorn & MacDonald, 2004; Malan, 2009; Meisalo, Sutinen & Torvinen, 2003). Such courses typically provide both printed and web-based materials, regular assignments with discussions on solutions, and tutors (Meisalo et al., 2003; Meiselwitz, 2002), lecture slides and laboratory worksheets before lectures, with audio recordings afterwards, both practical and tutorial exercises and solutions, and online quizzes (Chinn et al., 2010; Corney, Teague & Thomas, 2010). Some universities use online tools that provide formative and summative feedback to students about their concept comprehension (Chinn et al., 2010; Kaila et al., 2009). Automated assessment tools are used (Ala-Mutka, 2005; Ihantola, Ahoniemi, Karavirta & Seppälä, 2010), as well as other tools to enhance student learning, such as program or AV tools (Ben-Ari, Bednarik, Ben-Bassat Levy, Ebel, Moreno, Myller & Sutinen, 2011; Kaila, Rajala, Haavisto, Holvitie, Laakso & Salakoski, 2011).

To enhance online learning in MOOCs, Cooper and Sahami (2013) suggest using new tools such as algorithm visualizations (for example, AlgoViz, http://algoviz.org), or probability visualizations (see http://www.redblobgames.com), programming practice environments (such as Codingbat, http://codingbat.com, or Problets, http://problets.org) and editable coding visualizers (for example Online Python Tutor, http://www.pythontutor.com).

Additional approaches investigated for teaching programming online, include an electronic Adaptive Book composed of learning objects (LOs) that can be customized by instructors to deliver just-in-time interactive learning modules to students (Adamchik & Gunawardena, 2003; Adamchik & Gunawardena, 2005). It also includes a virtual workplace that provides an online interface development environment (IDE) and programming environment for students, and allows the instructor direct access to the student's workplace (Ng, Choy, Kwan & Chan, 2005); online environments to provide synchronized interaction between students and instructors (Cavus, Uzunboylu & Ibrahim, 2007; Domingue & Mulholland, 1997; El-Sheikh, 2009; Malan, 2009); blended learning (Robbins, 2008); and collaborative learning efforts (Tsai, 2012; Tsai, Shen & Tsai, 2011).

Visualization is used in several forms to enhance comprehension in distance teaching. Some institutions use videos to provide the classroom experience (Bruce-Lockhart & Norvell, 2007b; Murphy, Phung & Kaiser, 2008). Others recreate the classroom experience with virtual lectures and Web-conferencing (Bower, 2009; Koifman, Shimshoni & Tal, 2008; Malan, 2009). As in face-to-face teaching, both algorithm and program visualizations are used at times. Koifman, Shimshoni and Tal (2008) incorporate an AV system with virtual lectures and web conferencing, while Bruce-Lockhart and Norvell (2007b) use PV with interactive course notes. The PV system Jeliot3 has also been used in an online course (Čisar, Radosav, Pinter & Čisar, 2011).

Apart from the lack of direct contact that face-to-face teaching provides, most institutions in distance education teach programming in much the same way as in face-to-face institutions. However, the ‘distance’ in distance education, may add to the difficulties students experience.

2.4 Teaching introductory programming courses

In this section the teaching of introductory programming courses is discussed in general, without referring specifically to online courses.

2.4.1 The pedagogy of teaching introductory programming

Pedagogy deals with the manner in which teaching and learning are structured in order to enable desired learning outcomes. For introductory programming courses, the primary emphasis in the instructional setting usually falls on one of three main approaches: teaching programming as an application of skills in problem solving; learning a particular programming language; and code/system production (Pears, Seidman et al., 2007).

Teaching programming as problem-solving is based on Polya’s (1957) classic work in mathematics. Courses with this approach frequently focus on analysis and design before coding, and/or conceptualise programming tasks without using a specific programming language (Barnes, Fincher & Thompson, 1997; Falkner & Palmer, 2009; Fincher, 1999; Kiesmüller, 2009). Courses may start with teaching algorithms without writing code, and students using special didactically reduced, text-based, or visual languages to write their first programs (Kiesmüller, 2009). Acton, Voll, Wolfman and Yu (2009) describe the following two initiatives in problem-based teaching at the University of British Columbia: problem-based Just-in-Time-Teaching and problem-based peer learning. Queensland University of Technology also restructured their introductory programming course to focus on problem-solving (Corney, 2009; Corney et al., 2010).

Palumbo (1990) conducted an extensive literature review on the connections between learning programming languages and problem solving skills. He focused specifically on the transferability of learning a programming language to problem solving skills. Programming as problem solving, concerns two classes of problems, namely problems similar to ones that have been solved previously, and new problems that may be in a different application domain. Palumbo (1990) distinguishes between these two classes as well as between two types of skill transfer: near-distant and specific-generalised transfer. Near transfer refers to the ability to transfer skills and expertise to a new problem-solving domain with features similar to the domain in which proficiency and skill have already been obtained and established. Distant transfer is defined as the transfer of skills and expertise to a new problem-solving domain which is distinctly different from the problem-solving domain where expertise has already been acquired (Palumbo, 1990). Specific transfer refers to the transfer of one or more specific skills to a new-problem solving domain, while generalised transfer is defined as the transfer of general problem-solving techniques from one problem-solving domain to another. Both types of skill transfer are required in learning to program, but cannot be expected to happen in introductory programming courses since the time is too limited. Expert programmers as described by Winslow (1996) are characterised by both distant and generalised transfer skills. This takes time and experience to develop. The author notes that it takes approximately ten years to turn a novice into an expert (Winslow, 1996).

According to Robins, Rountree and Rountree (2003) typical introductory programming courses follow the second approach mentioned above. That is, they are ‘knowledge driven’ and focus on presenting knowledge about a particular programming language as well as the features supported by the paradigm to which that programming language belongs. Programming languages attempt to develop both declarative and procedural knowledge of students (Mandinach & Linn, 1986). The declarative aspects of programming knowledge refer to being able to state for example how a `for` loop works. Programming strategies refer to the way knowledge is used and applied, such as using the `for` loop appropriately in a program (Davies, 1993). Students are taught the command structure (declarative knowledge) of a programming language and are then presented with situations where they have to use this knowledge in strategically different ways (procedural knowledge) (Palumbo, 1990). Apart from studying the structure and syntax of the programming language, students also need to acquire certain schemas or plans, and the concepts of the programming paradigm. Schemas or plans in this context, refer to approaches to accomplish a task, for example how to determine the average of values (Robins et al., 2003). Common programming paradigms for introductory computer science courses are objects-first/object-oriented, functional or imperative/procedural (Davies, Polack-Wahl & Anewalt, 2011; Tew & Guzdial, 2010).

The required learning outcomes of programming courses are simple programs or software systems. If this is emphasised, as in the third pedagogical approach (code/system production), learning is based in the context of code and system development (Pears, Seidman et al., 2007). This corresponds to what Fincher (1999) describes as the ‘literacy approach’ where students are immersed in code development. For example, students do an ‘apprenticeship’ by reading, studying and extending programs written by experienced programmers (Astrachan & Reed, 1995) and developing working programs in laboratory settings under supervision (Vihavainen, Paksula & Luukkainen, 2011). Another example is live programming with a computer and projector to demonstrate the programming process in class and providing process recordings with added explanations (Bennedsen & Caspersen, 2005b). Situating programming assignments in the real-world domain also proves to be effective (Malan, 2010).

The explicit teaching of programming strategies is advocated as an alternative approach (Pears, Seidman et al., 2007; Robins et al., 2003; Soloway, 1986). An example where this was implemented successfully is described in De Raadt et al. (2009). Hughes (2012) reports on three different approaches to teach programming strategies, explicitly using the 3D, interactive programming environment Alice; the Python programming language; and an interactive flowcharting tool, Visual Logic. The author then concludes that Visual Logic produced the best results (Hughes, 2012). Teaching roles of variables, which represent certain stereotypical variable usage patterns as programming strategies, has also been successful (Sorva, Karavirta & Korhonen, 2007).

Based on an overview of research into programming, novice programmers, and learning and teaching in introductory computer science courses, Robins et al. (2003) recommend the following for a conventionally structured course with lectures, practical work and a conventional curriculum focused on knowledge:

- An introductory computer science course should be realistic in its expectations and develop systematically, by starting with simple facts, models and rules which are only expanded as students gain experience.
- Instruction should not focus only on the teaching of new language features, but also on how to combine and use those features, with special attention to basic program design.
- The fundamental mental models that underlie programming such as the notional machine, models of control, data structures and data representation, program design and problem domain should all be addressed, to prevent students from forming their own dubious models.
- Laboratory based, or practical programming tasks forming part of a typical introductory programming course, play an essential role to provide experience and reinforce learning, but should be based on and emphasise programming principles.

Robins et al. (2003) also recommend that the underlying issue of basic program design should be addressed with explicit naming and teaching of schemas/plans. This would be highly applicable in courses that base learning in the context of code and development. In courses teaching programming as problem-solving, covering language features and how to use and combine them should also be emphasised. In general, it may be beneficial to make control flow and data flow explicit in development environments or programming tools for teaching novices. For programming as problem-solving courses, Palumbo (1990) recommends that sufficient time should be allowed to develop students' programming language knowledge base and to use that knowledge in strategically different ways.

The pedagogy followed in the COS1511 module at Unisa, is to teach the C++ programming language as a basis for the follow-up courses in object-orientation. The students learn the structures and syntax of C++ while learning to develop code to solve problems. During this process it is important to ensure that students develop appropriate mental models for and of programming.

2.4.2 Mental models, threshold concepts and LEM in learning to program

It is not easy to learn how to program. In his section three concepts related to this issue are discussed, namely mental models, threshold concepts and LEM .

To produce compilable, executable programs in an appropriate and correct form, computing students are expected to learn how to successfully apply the following steps (McCracken et al., 2001):

- Abstracting the problem from its description.
- Generating the sub-problems, i.e. decomposing the problem according to the programming paradigm taught.
- Transforming sub-problems into sub-solutions by implementing the sub-solutions while following a specific programming paradigm.
- Re-composing the sub-solutions to generate a working program.
- Evaluating the resulting program and iterate the process accordingly.

Linn and Dalbey (1989) describe an ideal chain of cognitive accomplishments from programming instruction. The first link in this chain consists of the features of the language being taught. The second link is the design skills used to combine the language features to form a program. This includes templates or schemas and plans which provide students with a set of techniques to solve problems without inventing new code, as well the procedural skills of planning, testing and reformulating code to solve new problems. The third link is problem-solving skills which allow the student to abstract templates and procedural skills from the programming language taught and apply it to new programming languages and situations.

Du Boulay (1989) describes five overlapping domains that must be mastered in learning to program, namely –

- a general *orientation* to what programs are for and what can be done with them;
- the *notational machine*, a model of the computer with regard to executing programs;
- *notation*, that is the syntax and semantics of a particular programming language;
- *structures*, which are the schemas/ plans to execute specific tasks; and
- *pragmatics*, consisting of the skills of planning, developing, testing, debugging, and implementing programs.

These areas are all interrelated and each presents a potential source of difficulty.

The core elements characterising computer programming are data types, data operators, variables and constants, input/output control, sequential, iterative and conditional control structures. This list may be extended with data structures and abstraction, by modularised programming that incorporates parameter/message passing, as well as local/private and global/public variables. According to Farrell in (Naidoo & Ranjeeth, 2007), all of these concepts have to be mastered, regardless of which programming paradigm is adopted. Mastering structured programming is an essential step in learning object-oriented programming (Lo & Lee, 2013; Zhang, 2010). Other researchers agree that students would be unable to properly use and understand object-oriented techniques without appropriate mental models of variables and assignment (Ben-Ari, 2001; Ma, Ferguson, Roper & Wood, 2011). Furthermore, Naidoo and Ranjeeth (2007) assert that a deeper understanding of fundamental concepts would enable novices to adapt easier to processing new problem domains.

Once these core elements of programming have been mastered, students still need to learn and practise implementing them in designing and writing programs that can solve problems correctly. During this process students need mental models to guide and assist them.

2.4.2.1 Mental models

Kieras and Boviar (1984) define a mental model as some kind of understanding of how a device works in terms of its internal structure and processes. According to Isbell, Stein, Cutler, Forbes, Fraser, Impagliazzo, Proulx, Russ, Thomas and Xu (2010) a model is a representation of some information, physical reality or virtual entity that hides details and aspects not critical to the phenomenon being modelled. It can therefore be manipulated and simulated but still provides the ability to provide predictions or cause change in the modelled world. A mental model consequently is a person's internal representation of an entity, how it behaves and what responses can be expected from it.

Constructivist theory claims that students actively construct new knowledge by building recursively on the foundation of prior knowledge. In this process each individual creates his/her own mental model (Ben-Ari, 2001). Effective learning requires the development of viable mental models that match the actual design model and correctly explain the reality (Lui, Kwan, Poon & Cheung, 2004). Ben-Ari (2001) maintains that a novice programmer has no effective model of a computer. Therefore a viable mental model of a computer should be explicitly taught and programming exercises postponed until students have developed a viable model.

Robins et al. (2003) identify five mental models involved in writing a program, which overlap in some degree with the five domains to be mastered in programming (Du Boulay, 1989), namely –

- a model/knowledge of the programming language;
- an understanding/mental model of the problem domain, i.e. task the program should perform;
- a model or abstraction of the computer, whose properties are denoted by the programming language;

- a model of the intended program; and
- a model of the program as it actually is.

Wick (2007:509) describes the difficulty presented by the conceptual gap between the problem domain and the program in the following statement: “What makes programming hard is that the *language of the problem* does not match with the *language of the solution.*”

Winslow (1996) maintains that models are crucial to build understanding. These include models of control, data structures, and data representation, in addition to an understanding of the real world problem domain and program design. If the instructor does not provide them, students will develop their own mental models of programming concepts and what happens when computers execute programs (Sorva, 2008; Winslow, 1996). These mental models are frequently unstable and subject to change according to circumstances (Sorva, 2013). Models of control, data structures, and data representation refer to the knowledge or model of the programming language pointed out by Robins et al. (2003).

Winslow (1996) describes the process of program problem solving as taking place in the following steps:

- Understand the problem.
- Determine how to solve the problem, first in some way, and then in a computer compatible way.
- Translate the solution into a computer program.
- Test and debug the program.

Understanding the problem corresponds to building a mental model of the problem domain, while testing and debugging in turn, relate to reconciling the difference between the model of the intended program and the model of the program as it actually is (see Robins et al., 2003).

Novices need models which they can use to decompose the solution (the third stage above) into steps that they know how to translate into a computer program. A useful pattern as an example of a problem solving model is the three basic steps required for many simple problems, namely Input, Calculate, and Output (ICO). This can be extended as follows with a looping pattern: Initialise, Repeat for each entry (in list, table, or array), and Terminate (IRT) (Winslow, 1996). Such a problem solving model helps students to convert domain specific solutions into computer compatible solutions.

Mayer (1989) showed that providing a concrete model (the ‘notional machine’) of a computer to novices, can have a positive effect on their ability to code and use new technical information. His work supports Du Boulay’s idea of presenting novices with a notional machine as an idealised model of the computer represented by the constructs of the programming language (Du Boulay, O'Shea &

Monk, 1989), and ties in with the model or abstraction of the computer indicated by Robins et al. (2003).

In an extensive investigation on the mental models of assignment held by students in an introductory Java course, it was found that those students with a viable mental model performed considerably better in both programming tasks and exams than those with non-viable models (Ma, Ferguson, Roper, Ross & Wood, 2008; Ma, Ferguson, Roper & Wood, 2007; Ma et al., 2011). Some students required a period of time to change their faulty mental models. This confirms the importance of appropriate mental models for key programming concepts. It may also suggest that the concept of assignment might be a threshold concept.

2.4.2.2 Threshold concepts

Threshold concepts are seen as 'conceptual gateways', that is, difficult core concepts in a discipline which can block progress, but once understood, allows understanding of more advanced, previously inaccessible concepts (Meyer & Land, 2005). They are characterised by being:

- *transformative,* because they improve understanding of a concept significantly so that learners view the discipline differently;
- *irreversible,* since it is unlikely to forget or unlearn them;
- *integrative,* as it exposes previously hidden interrelatedness of concepts and allow learners to make new connections;
- frequently *troublesome,* because of the conceptual difficulty, being counter-intuitive or using language that is 'alien'; and
- *bounded,* indicating the limits or boundaries of the conceptual area or discipline (Meyer & Land, 2005).

In computer science, proposed threshold concepts cover state, program-memory interaction, levels of abstraction, pointers, the distinction between classes, objects and instances, recursion and induction, procedural abstraction and polymorphism (Rountree & Rountree, 2009). Khalife (2006:246) considers "a simple yet concrete model of the computer internals and how it operates during program execution," as the first threshold facing introductory programming students. Sorva (2013) also considers 'program dynamics' a major threshold for novice programmers. Research showing that an adequate mental model of program working storage (namely program-memory interaction) is required to transform introductory students from an end-user mind-set to a programmer mind-set, confirms this view (Vagianou, 2006). Note that crossing a threshold, is a gradual process taking place in a so-called 'liminal space' (Meyer & Land, 2005), the transitional period between learning a new concept and mastering it (Boustedt, Eckerdal, McCartney, Moström, Ratcliffe, Sanders & Zander, 2007; Eckerdal, McCartney, Moström, Sanders, Thomas & Zander, 2007; McCartney, Boustedt, Eckerdal, Moström, Sanders, Thomas & Zander, 2009; Meyer & Land, 2005). Students should be encouraged to actively and deliberately engage with a threshold concept to internalise it, for example by using PV tools to make students aware of the step-by-step process in program execution (Sorva, 2010). Mastering the relevant threshold concepts could allow a new mental model to be formed or an existing one to be adapted (Eckerdal, McCartney, Moström, Ratcliffe, Sanders & Zander, 2006).

2.4.2.3 Learning Edge Momentum (LEM)

Threshold concepts also tie in with the concept of LEM proposed by Robins (2010). LEM is based on the following two well-known and accepted factors: "firstly, that concepts in programming languages are tightly integrated; and secondly that we learn at the edges of what we already know" (Robins, 2010:55). The core of the LEM hypothesis is that the effects of successful or unsuccessful learning are self-reinforcing over time. When new concepts have to be learned, previous successful learning of related concepts will make it easier to master the new concepts, while unsuccessful learning will make it more difficult. This creates a momentum effect towards either success or failure. The tight integration of concepts in a programming language, exaggerates the LEM effect (Robins, 2010).

All of the above provides evidence that it is crucial that novices should master the core fundamental concepts and develop appropriate mental models in order to become proficient programmers.

2.4.3 Problems novices experience

Many of the difficulties novices experience can be related to lack of viable mental models for programming. In this section the problems novices experience are examined by referring to the differences between novices and experts, after which the concepts novices find difficult, are elaborated on.

2.4.3.1 The differences between novices and experts

Novices and experts develop code in different ways (Palumbo, 1990; Pears, Seidman et al., 2007; Robins et al., 2003). As mentioned previously, it takes about ten years to turn a novice into an expert. Expertise begins with general problem-solving skills and basic knowledge about the field, which grows with repeated practice (Winslow, 1996).

Various studies reviewed by Winslow (1996) concluded that novices –

- lack adequate mental models;
- are limited to superficial knowledge;
- have fragile knowledge (knows something but fails to use it when required);
- use general problem-solving strategies instead of strategies dependent on the specific problem; and
- approach programming through control structures, and in a line-by-line, bottom-up approach.

Robins et al. (2003) confirm this and add that novices spend little time on both planning and testing code. They attempt small ‘local’ fixes instead of reformulating code. They are often weak at tracking or tracing code and may not understand that programs execute sequentially. Their knowledge is more context-specific than general (Robins et al., 2003), as they tend to work with smaller, less-integrated information units (Palumbo, 1990). As a result, their problem-solving strategies can also be fragile (Robins et al., 2003), since they lack adequate organized, meaningful knowledge patterns in memory (Wiedenbeck, 2005). Furthermore, novices often do not realise their own shortcomings (Ala-Mutka, 2004).

Spohrer and Soloway (1989) provide an overview of the underlying problems novices experience. They identify three types of construct-based problems which hinder novices in learning the correct semantics of programming language constructs, as well as nine types of plan composition problems causing problems with planning and design, respectively entailing the following:

- Construct-based problems:
  - *Natural-language problem.* Novices confuse the semantics of programming-language constructs with the related natural-language words.
  - *Human interpreter problem.* Novices assume that the computer will interpret a construct in the way they intend it to be interpreted.
  - *Inconsistency problem.* When novices understand how a construct works in a certain situation, they may assume that it will do the same in a slightly different situation.
- Plan composition problems:
  - *Summarisation problem.* Only the primary function of a plan is taken into account, while the secondary functions may be overlooked.
  - *Optimisation problem.* Inapplicable optimisation may be attempted.
  - *Previous-experience problem (Plan-pollution).* Inappropriate aspects of previous plans may be used in a related-plan.
  - *Specialisation problem.* Abstract plans may be used inappropriately or instantiated incorrectly.
  - *Natural-language problem.* Mapping from natural language to a programming language may be incorrect.
  - *Interpretation problem.* Implicit problem specifications may be left out or only included when novices can easily retrieve plans for it.
  - *Boundary problem.* Novices find it difficult to specify correct boundary points when adapting a plan to specialised situations.
  - *Unexpected cases problem.* Uncommon, unlikely or boundary cases may be omitted.
  - *Cognitive load problem.* Minor but important parts of plans may be omitted, or plan interactions may be overlooked.

Soloway and Spohrer (1989) also report on general misconceptions held by novices. Novices frequently assume that the computer will do what they mean, rather than what they say, and do not realise the level of detail that needs to be specified (Du Boulay, 1989). Bonar and Soloway (1989) show that novices' pre-programming knowledge about standard tasks in step-by-step natural language, plays an important role in relation to the bugs in their programs, especially if their programming knowledge is fragile. Spohrer and Soloway (1989) found that a large percentage of program bugs are caused by a few bug types; and that most bugs are the result of plan composition problems (putting the pieces of a program together) and not of construct-based problems (misconceptions about language constructs).

Experts, in contrast (Winslow, 1996) –

- have many mental models which they select and combine in resourceful ways;
- have a deep, hierarchical, many-layered knowledge of their subject with explicit maps between the layers;
- apply all their knowledge;
- work forward from the givens when processing a task in familiar areas and develop sub-goals hierarchically, but fall back on general problem-solving techniques when faced with unfamiliar problems;
- recognise problems with a similar solutions more easily;
- tend to approach programs through data structures or objects;
- use abstract algorithms rather than language specific syntax;
- work faster and more accurate; and
- have better syntactical and semantic knowledge and better tactical and strategic skills.

Robins et al. (2003) add to the above that experts have efficiently organised and specialised knowledge representations; organise their knowledge based on functional characteristics instead of superficial details; use both general and specialised problem-solving strategies; use specialised plans and a top-down, breadth-first approach to deconstruct and understand programs; and are flexible in their approach to understand programs and willing to discard dubious hypotheses. Wiedenbeck (2005) confirms that efficient programming knowledge organisation distinguishes experts from novices.

In contrast to novices, experts spend much of their time on planning. Experts are aware of the advantages of testing their code and have well-developed strategies to design tests to expose all possible problems. Novices frequently test only the obvious and may neglect to test all of their code. Experts consider large-scale as well as minor changes when required to modify their programs, while novices tend to attempt 'local' fixes (Linn & Dalbey, 1989).

Experts use sophisticated problem-solving skills such as decomposition, analogical reasoning and systematically plan, code and debug their programs. Novices classify tasks and write programs according to surface characteristics while experts use the general concepts and underlying structures to solve programing problems (Kurland, Pea, Clement & Mawby, 1989).

In summary, while experts use sophisticated knowledge representations and problem-solving strategies, novices experience difficulty in basic program planning, and their programming specific knowledge is often fragile (Pears, Seidman et al., 2007; Robins et al., 2003). Even if they know the syntax and semantics of individual statements, they do not know how to combine these into valid programs (Winslow, 1996). To assist novices in becoming experts, educators should take note of the recommendations in Robins et al. (2003), and pay special attention to assist novices in developing appropriate mental models for programming.

2.4.3.2 What do novices find difficult

Much of the research in computing education (CER) focuses on why students find learning to program difficult, and what topics cause difficulties, as well as on factors predicting student success. This can be seen from the following themes revealed by surveys of CER:

- Theories and models (pedagogy) of teaching/learning (Clancy, Stasko, Guzdial, Fincher & Dale, 2001; Palumbo, 1990; Pears, Seidman, Eney, Kinnunen & Malmi, 2005; Pears, Seidman et al., 2007; Robins et al., 2003; Sheard et al., 2009; Valentine, 2004).
- Ability/aptitude/understanding, including the difference between novices and experts (Clancy et al., 2001; Palumbo, 1990; Robins et al., 2003; Sheard et al., 2009).
- Teaching/learning and assessment techniques (Clancy et al., 2001; Palumbo, 1990; Pears et al., 2005; Pears, Seidman et al., 2007; Robins et al., 2003; Sheard et al., 2009; Valentine, 2004).
- Tools to assist with teaching/learning and assessment (Clancy et al., 2001; Palumbo, 1990; Pears et al., 2005; Pears, Seidman et al., 2007; Robins et al., 2003; Sheard et al., 2009; Valentine, 2004).

For the purpose of this study the topics that novices find difficult to understand is important, as the purpose of the tutorial developed for this study is to address some of those topics. A brief summary of the reasons why novices fail is presented, before the topics that novices find difficult are expanded on.

The list that follows does not claim to be comprehensive, but among the reasons why novices fail to learn to program, the following are listed from the literature:

- fragile programming knowledge and in particular, fragile problem-solving strategies (Robins et al., 2003);
- misconceptions about programming constructs (Soloway & Spohrer, 1989);

- lack of problem-solving skills (McCracken et al., 2001; Miliszewska & Tan, 2007);
- inability to organise programming knowledge efficiently (Wiedenbeck, 2005);
- lack of prior experience, such as previous abstraction experience, background deficiencies in particular kinds of mathematics such as discrete mathematics and logic (Kinnunen et al., 2007; Pears, East et al., 2007; Pears, Seidman et al., 2007);
- lack of a viable mental model of programming and the computer, possibly due to lack of programming experience (Kinnunen et al., 2007; Miliszewska & Tan, 2007; Robins et al., 2003);
- the difficulty of the curriculum and course content as well as the teaching methods (Jenkins, 2002; Kinnunen & Malmi, 2008; Kinnunen et al., 2007; Miliszewska & Tan, 2007; Pears, East et al., 2007);
- students' attitude and motivation; behaviour, such as deep learning versus surface learning; and expectations, such as lack of self-efficacy[2] (Ala-Mutka, 2004; de Raadt, Hamilton, Lister, Tutty, Baker, Box, Cutts, Fincher, Hamer & Haden, 2005; Jenkins, 2002; Kinnunen & Malmi, 2008; Kinnunen et al., 2007; Pears, East et al., 2007; Wiedenbeck, 2005);
- intrinsic student abilities, such as natural level of ability and ways of thinking (Ala-Mutka, 2004; Jenkins, 2002; Kinnunen et al., 2007; Pears, East et al., 2007); and
- inability to read and understand program code (Lister et al., 2004; Mannila, 2006).

Some novices are effective and some ineffective. Effective novices learn to program without too much assistance; ineffective novices do not learn, despite disproportionate effort and personal attention. The difference in strategies, rather than knowledge, is probably the most important difference between effective and ineffective novices. Unsuccessful novices frequently stop when stuck. Instead of exploring different ideas; they do not trace, or do so half-heartedly; try small changes instead of considering all of the code; and neglect to break problems down into parts, or err in doing so (Perkins et al., 1989).

Many of the specific problems novices experience have been identified in the latter part of the previous century already, as can be seen from Soloway and Spohrer's (1989) compilation of several studies that report on novices' understanding of specific language features and how they use them. Samurçay (1989) investigated novices' concepts of a variable and using it. He reports that initialisation is a complex cognitive operation and that novices understand reading (obtaining external input) better than initialisation. Initialisation is also more complex than updating and testing variables, which are on the same complexity level. Du Boulay (1989) too, points out various difficulties novices

[2] Perceived self-efficacy is "beliefs in one's capabilities to organise and execute the courses of action required to produce given attainments" (Bandura, 1997:3).

experience with the assignment statement, such as inappropriate analogies. Hoc (1989) found that certain kinds of abstractions can lead to errors in constructing conditional statements. In their analysis of bugs in simple Pascal programs, Spohrer, Soloway and Pope (1989) found that errors associated with loops and conditionals are more common than those with input, output, initialisation, update, syntax/block structure and planning. Soloway, Bonar and Ehrlich (1989) studied how novices use loops, and concluded that they preferred to use loops that first read, then process rather than using process/read loops, since this concurred with their natural strategy. Du Boulay (1989) points out that novices frequently have trouble with `for` loops because they fail to understand that the loop control variable is incremented in each loop cycle. He also notes the problems novices experience with using arrays, especially understanding the difference between subscripts and the values in the array cells (Du Boulay, 1989). Kahney (1989) showed that novices may acquire different models of recursion, of which most are incorrect. Kessler and Anderson (1989) found that novices were better able to write recursive functions after studying iterative functions first, but not vice versa. They concluded that novices' difficulty in understanding flow of control, is due to their inadequate mental models of the task.

Despite these problems having been exposed for a quarter of a century, they persist, as can be seen from more recent research. In imperative-first courses students seem to experience problems with two core concepts, assignment and sequence, and recursion/iteration (Bornat et al., 2008). Simon (2011) found that it seems as if many students in their first, second and even third programming courses do not understand the semantics of the assignment statement, or that a sequence of statements are executed sequentially, and possibly both. Jimoyiannis' (2013) study confirms that many novice programmers have mathematical-like mental models about variables and the assignment statement. Sorva (2008) too, points out various misunderstandings students have about primitives and object variables. This may be due to common misconceptions about variables and confusion between assignment and equality based on their prior knowledge of algebra (Khalife, 2006; Sorva, 2008). Nevertheless, it keeps them from understanding a standard swap operation and will make it more difficult to learn further concepts (Simon, 2011) as proposed by the LEM hypothesis (Robins, 2010). Without proper mental models for variables and assignments, students will also be unable to understand and implement object-oriented techniques (Ben-Ari, 2001; Farrell, 2006; Ma et al., 2011; Sorva, 2008).

In an investigation focused on topics in object-oriented programming second-year students find difficult, Milne and Rowe (2002) conclude that students struggle mostly with pointer and memory topics, because they do not understand what happens in memory when their programs are executed. This will continue to be a problem, unless they develop a clear mental model of how their program is working in terms of how it is stored in memory and how the objects in memory relate to each other.

In an objects-first course, Ragonis and Ben-Ari (2005) found that novices experience difficulties in understanding program flow and sequential program execution, because they do not understand the difference between the integrated development environment (IDE) and the execution of a program. They struggled to understand that methods could be invoked more than once, where parameters receive values, and where the return value of a method goes. They also found it difficult to comprehend the need for input instructions, as well as the relationship between constructor declaration, invocation and execution (Ragonis & Ben-Ari, 2005). This confirms Milne and Rowe's (2002) observation that students need a clear mental model of program-memory interaction to master object-oriented programming. It also ties in with program-memory interaction as a threshold concept (Rountree & Rountree, 2009).

In a Delphi process[3] the 11 most important and difficult concepts in introductory computing courses have been identified, in order of most difficult and most important, as – (Goldman, Gross, Heeren, Herman, Kaczmarczyk, Loui & Zilles, 2008; Goldman, Gross, Heeren, Herman, Kaczmarczyk, Loui & Zilles, 2010)

- abstract pattern recognition and use;
- debugging, exception handling;
- functional decomposition, modularisation;
- conceptualise problems, design solutions;
- designing tests;
- inheritance;
- memory model, references, pointers;
- parameter scope, use in design
- procedure design
- recursion, tracing and designing; and
- issues of scope, local vs. global (Goldman et al., 2008; Goldman et al., 2010).

As part of the same study, Kaczmarczyk, Petrick, East and Herman (2010) identified the following four themes emerging from students' misconceptions:

- Misunderstanding the relationship between language elements and underlying memory usage.
- Misunderstanding the process of `while` loop operation.
- Lacking a basic understanding of the object concept.
- Inability to trace code linearly.

Kaczmarczyk, Petrick, East and Herman (2010) elaborate on the first theme (misunderstanding the relationship between language elements and underlying memory usage) in Table 2.1 below. From the

[3] A Delphi process is a structured multi-step process that uses a group of experts to achieve a consensus opinion (Dalkey & Helmer, 1963).

perceptions that students hold about memory allocation as identified in Table 2.1, it is clear that the misconceptions are based on inappropriate or absent mental models of variables and assignments.

Table 2.1 Misconceptions about the relationship between language elements and underlying memory usage (Kaczmarczyk, Petrick, East and Herman 2010)

Language element	Underlying memory usage
Semantics to semantics	Student applies real-world semantic understanding to variable declarations.
All objects same size	Student thinks all objects are allocated the same amount of memory regardless of definition and instantiation.
Instantiated no memory allocation	Student thinks no memory is allocated for an instantiated object.
Uninstantiated memory allocation	Student thinks memory is allocated for an uninstantiated object.
Off by 1 array construction	Student thinks an array's construction goes from 0 to length, inclusive.
Primitive no default	Student thinks primitive types have no default value.
Primitives don't have memory	Student thinks primitives without a value have no memory allocated.

Dropout students identified the most difficult topics as designing one's own code, exception handling, handling files, arrays, identifying structures in given code, adopting the programming style required in the course and transferring one's own thinking into programing language (Kinnunen & Malmi, 2008). At Victoria University in Melbourne, Australia, novices found classes and methods, graphical user interfaces and event handling the most difficult; followed by iteration, selection, and input/output (Miliszewska & Tan, 2007). The technicalities of programming were also perceived as difficult. In Malaysia, novices without prior programming experience considered the most difficult topics in decreasing order to be designing a program to solve a certain task, dividing functionality into procedures, learning the programming language syntax, finding bugs in their own programs, understanding basic concepts of programming structures, using the IDE and gaining access to computers/networks (Tan, Ting & Ling, 2009). Butler and Morgan (2007) confirm that students find topics of a more conceptual nature more difficult both to understand and to implement. These include object-oriented concepts and design, program design and arrays.

Dale (2006) identified four categories of difficult topics, namely problem-solving and design, general programming topics, object-oriented constructs and student maturity (or rather, lack thereof). Based on the feedback related to the first and fourth categories, the results of her study suggest that students may not have developed the logical thought processes that are required for problem-solving. These higher-order skills are also required for the third category. The second category includes control structures, I/O, parameters and recursion with parameters, arrays, looping and files (in descending order of difficulty) indicated as the most difficult topics. Concrete examples and better teaching tools are suggested to improve learning (Dale, 2006).

In an international survey, Lahtinen, Ala-Mutka and Järvinen (2005) identified the most difficult issues in programming as understanding how to design a program to solve a certain task; dividing functionality into procedures, functions and/or classes; and finding bugs in own programs. All of these require understanding larger entities of a program instead of only some details. Recursion, pointers and references, abstract data types, error handling, and using language libraries were singled out as the most difficult programming concepts. Learning to *apply* rather than understanding basic concepts appears to present the biggest problem. This work confirms the findings by Soloway and Spohrer (1989), Milne and Rowe (2002) and Dale (2006).

Based on the work by Milne and Rowe (2002), Lahtinen et al. (2005) and Tan, Ting and Ling (2009), Piteira and Costa (2012) summarised topics in introductory programming courses from the highest level of student comprehension to the lowest, as being – selection structures; variables (lifetime/scope); loop structures; operators and precedence; structured data types; abstract data types; recursion; pointers and references. This concurs to a large extent with the work by Ben-Ari (2001), Bornat et al. (2008), Butler and Morgan (2007), Dale (2006), Farrell (2006), Goldman et al. (2008), Goldman et al. (2010), Hertz and Ford (2013), Jimoyiannis (2013), Kaczmarczyk et al. (2010), Khalife (2006), Kinnunen and Malmi (2006), Lahtinen et al. (2005), Ma et al. (2011), Miliszewska and Tan (2007), Milne and Rowe (2002), Ragonis and Ben-Ari (2005), Simon (2011), Soloway and Spohrer (1989) and Sorva (2008) investigating the topics that novices find difficult discussed/described above.

Schulte and Bennedsen (2006) investigated what teachers teach in introductory programming and came to the conclusion that the majority of the 'classic' topics (such as iteration and syntax) are taught at the same level, with the same difficulty and the same relevance regardless of which paradigm (imperative or OO) is followed. An interesting finding was that most teachers consider a mental model of the notional machine less important, but despite that, believed a hierarchy of object-interaction presented as the basis for a notional machine in OO, was important (Schulte & Bennedsen, 2006). Related to this is, Herz and Ford's (2013) investigation in the importance an instructor ascribes to a topic and the time spent teaching a topic as underlying factors that influence introductory student leaning. Little correlation has been found between time spent on teaching a topic and students' abilities related to that topic. In contrast, novices' abilities on a topic correlate to a large extent positively with how important the instructor deems the topic to be, with the exception of control structures, subroutines/functions and types. This suggests that these are difficult topics to master, once again confirming previous research.

Considering the problems highlighted by the research presented above, it seems as if students experience the same problems after the introduction of OO, as they did before. Many of these problems originate in a lack of an appropriate mental model of a running program, which Khalife

(2006) considers the first threshold facing introductory programming students. An inadequate comprehension of program-memory interaction is reflected in the problems students experience with memory topics such as variables, assignment, data structures, parameters, objects, pointers and references. Lack of understanding the flow of control in a running program is reflected in problems with the execution sequence, control structures, procedures and recursion. Students also struggle with program design and debugging. The complexities of OO may even introduce more problems since more material have to be covered in introductory courses, with less time allocated to basic concepts such as control structures. Event-handling and class methods also add an additional layer of complexity (McCauley, Fitzgerald, Lewandowski, Murphy, Simon, Thomas & Zander, 2008).

2.5 Tracing

One of the mechanisms to assist with clearing up misconceptions held by novices (see section 2.4.3.2 What do novices find difficult) and developing mental models (as discussed under the Section 2.4.2.1 Mental models), is to teach them tracing. In the following sections tracing itself is defined, the reasons why tracing is important are explained, difficulties novices experience with tracing as well as the advantages of teaching novices to trace are pointed out.

2.5.1 Tracing defined

Tracing is the "mental simulation of a program execution" (Vainio & Sajaniemi, 2007:78), that is, to imitate at some level of detail and/or accuracy, the process of a computer executing code (Fitzgerald, Simon & Thomas, 2005). Tracing can be done in various ways, such as mentally, by comparing output with code, by tracking the values of variables on paper, using temporary statements to print variables' values, and using a debugger (Murphy, Lewandowski, McCauley, Simon, Thomas & Zander, 2008). Tracing can also be done at two levels, namely 'concrete simulation' where code is traced with the actual *values* of variables; and 'symbolic simulation', that is on a higher level, where the different *steps* in which the program is executed are simulated (Détienne & Soloway, 1990).

Concrete simulation corresponds to what Cogan and Gurwitz (2009) call memory tracing. This is the activity where a programmer 'executes' a program (or segment) on paper, by tracing the statements one by one, in the process tracking the values of all variables, and how they change during program execution. The purpose of this action is typically to debug a program, or to understand what the program does (Cogan & Gurwitz, 2009), and especially to test boundary or error conditions (Fitzgerald et al., 2005). Memory tracing differs from hand-checking a program. With hand-checking, the calculations to solve a problem are done independently of the program and these results are then compared to the program's final output (Cogan & Gurwitz, 2009). Memory tracing is also called 'close tracking' (Perkins et al., 1989), or a 'walkthrough' – hand executing code in meticulous detail (Lister et al., 2004).

Mentally comparing output with code, using statements to print variables' values, and using a debugger, resemble symbolic simulation. Symbolic tracing frequently involves plan or pattern recognition (Détienne & Soloway, 1990; Fitzgerald et al., 2005), one of the abilities that distinguishes experts from novices.

2.5.2 The purpose of tracing

Tracing plays an important role in program comprehension. When a programmer reads a program, he/she constructs two mental models. The first model is a low-level program model based on the structure of the program code as indicated by control flow relationships such as loops and conditionals. The second model is a higher-level domain model based on the data flow which reflects the main purpose of the program or the application (Mannila, 2006; Vainio & Sajaniemi, 2007). These two mental models of a program correspond with the comprehension that the two levels of tracing (concrete simulation and symbolic simulation) can produce. Novices typically find it difficult to abstract from the code to construct a domain model, because they tend to have concrete mental representations of the program code and understand concepts in isolation (Mannila, 2006). They find it difficult to "see the forest, not just the trees" (Lister, Simon, Thompson, Whalley & Prasad, 2006:122) due to their lack of experience and the complexity of symbolic tracing (Vainio & Sajaniemi, 2007).

Tracing is also an important strategy in debugging (Murphy, Lewandowski et al., 2008). Ducassé and Emde (1988) identified the following seven types of knowledge required for successful debugging: knowledge of the intended program, knowledge of the actual program, understanding of the programming language, general programming expertise, knowledge of the application domain, knowledge of bugs, and knowledge of debugging methods. Knowledge of the actual program and the intended program refers to input/output, program behaviour and implementation. The majority of competent debuggers are competent programmers, but not all good programmers are good debuggers (Ahmadzadeh, Elliman & Higgins, 2005; Fitzgerald, Lewandowski, McCauley, Murphy, Simon, Thomas & Zander, 2008). The key factor that distinguishes good debuggers from good programmers is knowledge of the actual program implementation. This indicates that the ability to read and understand other people's programs is an essential skill to acquire in the journey from novice to expert (Ahmadzadeh et al., 2005).

In line with the findings by Ahmadazeh et al. (2005) and Fitzgerald et al. (2008), several studies showed that students who cannot trace or read code, usually cannot explain code, and also that students who perform reasonably well at code writing tasks, can typically both trace and explain code (Lister et al., 2010; Lister et al., 2009; Lopez et al., 2008; Philpott et al., 2007; Rountree et al., 2005; Sheard et al., 2008; Venables et al., 2009). Acton et al. (2009) also found that students who cannot draw memory representations of data structures, achieve poor grades. This is not a recent conclusion.

Soloway (1986:857) found that “designers and maintainers who did not carry out simulations did not develop an effective design or an effective enhancement.”

Studies by the BRACElet project (Clear et al., 2009; Lister et al., 2010; Whalley & Lister, 2009) suggest the possibility that a novice programmer develops skills in a hierarchical order, as follows: The novice first acquires the ability to read, namely to trace code. Once this competency becomes reliable, the capacity to explain code develops. When students are reasonably capable of both reading and explaining, the skill to systematically write code emerges. The skills in this hierarchy do not necessarily develop in a strict order, but instead reinforce each other and develop in parallel. Furthermore, students require a certain minimal competence at tracing and explaining before exhibiting a minimal competence to systematically write code (Lister et al., 2010; Lister et al., 2009; Venables et al., 2009; Whalley & Lister, 2009). See Chapter 3 for more on the BRACElet project.

Kumar (2013) found that solving code-tracing problems improved students’ code-writing skills. The study used selection statements (`if` and `if-else` statements). The improvement affected mainly the language syntax skills of students and those who spent more time on the code-tracing exercises showed greater improvement.

Carbone, Hurst, Mitchell and Gunstone (2009) identified five technical skills influencing student learning of programming. Three of these, close tracking (tracing), tinkering and debugging skills, are interdependent. If students can trace their code, they can localise problems and understand the issues, and then make informed changes.

From the above, it is clear that learning to trace programs is an important stepping stone in learning to program as well as in learning to debug programs.

2.5.3 Difficulties novices have with tracing

Fitzgerald et al. (2005) investigated strategies that students follow to trace code and classified these strategies according to Bloom’s taxonomy (Krathwohl, 2002) and the Approaches to Study Inventory (see Tait & Entwistle, 1996). They found that successful tracing depended not only on which strategy was followed, but rather on ‘how well’ the strategy was executed (Fitzgerald et al., 2005). Their classifications imply that seeking higher levels of meaning from the code (symbolic tracing) falls into the higher levels of Bloom’s taxonomy and that it requires deep learning strategies. This explains why novices find symbolic tracing more difficult.

Novices often use tracing ineffectively, for example by using print statements to trace flow of control without including other information such as the values of variables (Murphy, Lewandowski et al., 2008). Perkins et al. (1989) maintain that accurate tracing (close tracking) is a mentally demanding activity that requires understanding of the language primitives and the rules for flow of control. The following factors influence the ability to track accurately (Perkins et al., 1989):

- Motivation, because students do not understand the importance of tracking and lack confidence in doing it.
- A flawed understanding of the programming language constructs.
- Projecting intentions on the code that prevents correct mapping from the code to the output, that is students expect the code to do what they intend it to do.
- Cognitive style differences – students who naturally work methodically and reflectively may be better at tracing than those who have a trial-and-error approach.

Vaino and Sajaniemi (2007) found that novices have two types of difficulties with diagrams used to trace programs, namely being unable to draw diagrams that describe the program state and being unable to use diagrams in program tracing. They argue that students should have automated the processing of syntactic details so that they understand the concepts depicted in diagrams, before they will be able to draw and use such diagrams.

2.5.4 The advantages of teaching novices to trace

Several studies show that teaching novices to trace can be beneficial. Cogan and Gurwitz (2009) claim that teaching students tracing skills early in their introductory programming courses improved the through-put rate. Kollmansberger (2010) found an increase of 40% in course completion on introducing a tool that emphasizes tracing the step-by-step execution of each statement interactively. Hertz and Jump (2013) organised their first and second year programming courses around program memory traces that depict all of a program’s accessible memory (stack, heap and static) on paper. This improved students’ programming grades as well as retention and pass rates. These examples seem to confirm Robins’ (2010) LEM effect, as well as the findings by the BRACElet studies (Lister et al., 2009; Venables et al., 2009).

Tracing forces students to engage with their programs on a deeper level. First-year students without prior programming experience often treat source code as simple text, instead of an executable program meant to accomplish a task. They then simply aim to create a program that compiles without syntax errors, without considering the actual purpose of the program. Teaching them to trace, focus their attention on what the program actually does (McCracken et al., 2001). Manually performing a memory trace forces the programmer to understand the role of every statement in the program, and makes the process more concrete (Cogan & Gurwitz, 2009). Thomas, Ratcliffe and Thomasson (2004) also conclude that students have to construct diagrams to trace code themselves in order to make sense of the code. This confirms the recommendation by Perkins et al. (1989) to trace written code in order to comprehend what it actually does, rather than what it may seem to do on first inspection.

Tracing a program allows the novice to create a mental model of the program and predict its behaviour, an essential part of program comprehension (Robins et al., 2003).

Teaching students to trace can play a motivational role. Thomas et al. (2004) maintain that once students discover the value of constructing tracing diagrams, it encourages them to continue doing so. Manual tracing teaches them a rigorous attention to detail which assists both in avoiding errors and finding errors more quickly. This helps them overcome initial technical and emotional barriers to the challenging demands of generating correct code and better prepares them to master more complex algorithms (Cogan & Gurwitz, 2009).

Perkins et al. (1989) recommend teaching a mental model of the computer, in the form of a notional machine (Du Boulay et al., 1989) to assist with both close tracking and decomposing problems in ways appropriate to the language's capabilities. Vainio and Sajaniemi (2007) also recommend teaching the notional machine to students, as well as how to form a mapping between diagrams and program code. Correspondingly, tracing code may assist students in forming a mental model of the computer so that they comprehend that program execution is sequential, that the order of statements matter and that statements do not execute in parallel, that is the computer does exactly what it is told (McCauley et al., 2008).

Lister (2007:138) maintains that students should be taught and thoroughly assessed on the "low-level skill of tracing through code", similar to Soloway's (1986) plea that simulation should be explicitly taught to students. Two multi-national studies (Lister et al., 2004; Lister et al., 2009) likewise propose that manual memory tracing be emphasized and taught explicitly in introductory computer science courses. Cogan and Gurwitz (2009) recommend that students should be trained to be proficient at doing manual memory tracing before being introduced to automated debuggers, since memory tracing enables students to form a better connection with the inner workings of their code, than when using debuggers or print statements.

Teaching novices how to trace their programs can therefore play a valuable role in developing their programming skills. Tracing is also an important debugging skill, and as such contribute to writing good code as well as in maintaining code written by others.

2.6 Visualization

This section provides the background on visualization with an overview of SV in general, and in particular of SV in education. The success of visualization in education is also examined.

2.6.1 Software visualization – an overview

One of the tools used to enhance the comprehension of programming concepts and facilitate tracing, is SV. According to Petre and Quincey (2006:1), "software visualization uses visual representations to make software more visible". Visualization refers to the graphical display of information in order to assist human comprehension of and reasoning about that information. SV specifically refer to graphical techniques to illustrate different elements of software such as source code, software structure, runtime behaviour, component interaction, or software evolution, with the aim to enhance comprehension (Petre & Quincey, 2006). Price, Baecker and Small (1993:1) define SV as using "typography, graphic design, animation and cinematography with modern human-computer interaction (HCI) technology to facilitate both the human understanding and effective use of computer software".

A number of taxonomies to classify SV systems have been proposed (see Maletic, Marcus & Collard, (2002); Myers, (1990); Price et al., (1993); Roman & Cox, (1993); Stasko & Patterson, (1992)). Each of these researchers base their classification on different aspects such as the purpose of the visualization (Myers, 1990); scaled dimensions (Stasko & Patterson, 1992); what is visualized (Price et al., 1993); similarity between what is represented and how it is represented (Roman & Cox, 1993); or tasks (Maletic et al., 2002). More recently some proposed taxonomies focused on classifying SV systems for debugging purposes (Sensalire, Ogao & Telea, 2008), algorithm animation languages (Karavirta, Korhonen, Malmi & Naps, 2010) or educational purposes (Mutua, Wabwoba, Ogao, Anselmo & Abenga, 2012; Xu, Chen & Liu, 2009).

Aspects of software that can be visualized include the architecture, the design, the algorithm, the source code, the data, execution/trace information, measurements and metrics, documentation, and process information (Maletic et al., 2002; Petre, Blackwell & Green, 1998). Specific aspects of software design and development represented with SV include object-oriented aspects, formalisms, metrics, slicing, XML, software evolution, data mining in software systems, software security analysis, and algorithm and software engineering education (Gračanin, Matković & Eltoweissy, 2005). Visualization can be done in terms of code, tables, diagrams, charts, visual metaphors (such as icons, figures, images, and worlds) and can have various attributes (such as interactive, static, dynamic, on-line or off-line views, multiple views, drill-down capabilities, multiple abstraction levels). It can be rendered on paper or various types of monitors (Maletic et al., 2002). Gračanin et al. (2005) discuss examples of two-dimensional and three-dimensional SV representations as well as virtual environments.

Experts and novices use visualizations for different purposes. Experts use SV mainly for three activities, namely code comprehension, debugging and design reasoning (Petre & Quincey, 2006). In the field of code comprehension SV are mostly used for maintenance purposes (Gračanin et al., 2005;

Petre & Quincey, 2006). SVs for non-experts are typically intended to provide an idea of an expert's imagery or an expert's reasoning process, how computers work or programs are executed, and to provide additional views of complex relationships novices find difficult to comprehend (Petre et al., 1998).

2.6.2 SV in education

A vast array of SV tools exists. SV tools used for novices in introductory programming courses include visual programming environments, microworlds, AV systems, and PV systems (Helminen & Malmi, 2010). Visual programming environments provide a simplified graphical interface to construct programs with, instead of writing code. This eliminates the effort and complexity involved with the syntax of a programing language and allows learners to concentrate on essential programming concepts without being distracted by having to cope with syntax and error messages as well. JPie (Goldman, 2004) and Karel Universe (Bergin, 2006) are examples of visual programming environments. RAPTOR (Carlisle, 2009; Carlisle, Wilson, Humphries & Hadfield, 2005) is a visual programming environment that uses flowcharts and UML (Unified Modeling Language) diagrams to create programs. BlueJ (Kölling, Quig, Patterson & Rosenberg, 2003) is another IDE that defines classes and their relationships with a graphical UML-like notation. BlueJ also has a built-in debugger that allows single-step execution and an object inspector (Bennedsen & Schulte, 2010).

Microworlds also provide a simplified graphical interface with a specialised simplified teaching language integrated with a world of objects that can be explored and manipulated with a limited set of operations. Some examples of microworlds are Alice (Powers, Ecott & Hirshfield, 2007), Jeroo (Sanders & Dorn, 2003) and Greenfoot (Henriksen & Kölling, 2004; Kölling, 2008a).

AV and PV systems are used to visualize algorithms, source code, data and execution/trace information. Price et al. (1993) distinguishes between AV and PV. AV animates an algorithm in terms of its high-level operations to enhance understanding of its procedural behaviour (Hundhausen et al., 2002), while PV visualizes the actual implemented code, showing the effect of each operation (Röβling et al., 2008). Taylor and Pountney (2009:204) define animation as "the rapid display of a sequence of images in order to create an illusion of movement", due to the phenomenon of persistence of vision. Algorithm animation tools thus capture the dynamic behaviour of code by simulating the algorithm. They typically use conceptual visualizations of the data structures involved, to highlight relationships instead of reflecting the actual contents of computer memory and are intended for lecturing purposes (Helminen & Malmi, 2010). Examples of AV systems include Animal (Röβling & Freisleben, 2002), JHAVÉ (Naps, 2005), ALVIE (Crescenzi & Nocentini, 2007), jGRASP (Cross II & Hendrix, 2007) and TRAKLA (Nikander, Korhonen, Seppälä, Karavirta, Silvasti & Malmi, 2004). PV tools focus on the visualization of static structures such as the content of variables or the stack frame; or display the dynamic aspects of program execution statement by statement (Pears, Seidman et al., 2007). PV tools assist program comprehension and debugging (Helminen & Malmi, 2010). In PV systems animation is used to show the sequential aspects of the software in execution. Examples of PV tools include Jeliot 3 (Ben-Ari et al., 2011; Moreno & Joy, 2007), VIP (Virtanen, Lahtinen & Järvinen, 2005), Teaching Machine (Norvell & Bruce-Lockhart, 2004), Jype (Helminen & Malmi, 2010) and ViLLE (Rajala, Laakso, Kaila & Salakoski, 2007). PVs are typically used to teach programming structures in introductory courses using a specific programming language, while AVs are used in courses on algorithms and data structures (Lahtinen, 2008). Therefore, in introductory programming courses PV is used more often than AV (Lahtinen, Jarvinen & Melakoski-Vistbacka 2007).

Although a considerable number of SVs have been developed, few of them are used by teachers or lecturers other than the developers themselves. Although instructors may agree that visualizations can help learners learn computer science, they are not always sufficiently convinced of the educational effectiveness of visualizations to use them (Hundhausen et al., 2002; Knobelsdorf, Isohanni & Tenenberg, 2012; Naps, Cooper, Koldehofe, Leska, Rossling, Dann, Korhonen, Malmi, Rantakokko, Ross, Anderson, Fleischer, Kuittinen & McNally, 2003; Shaffer, Akbar, Alon, Stewart & Edwards, 2011). Various reasons for not using SV are cited, such as the difficulty and lack of time to find, download, install, learn, adapt, integrate into the course, and teach the students to use and maintain it according to the study material used at the institution (Ben-Bassat Levy & Ben-Ari, 2007; Domingue, 2002; Hundhausen et al., 2002; Naps et al., 2003a; Pears, East et al., 2007; Röβling et al., 2008; Shaffer et al., 2011). Platform dependence and the level of difficulty to integrate and adapt the visualization to the course format and content, are also major reasons why the use of SV are not more widespread (Naps et al., 2003a; Shaffer et al., 2011). Reiss (2005) proposes that the reason why SV is not more successful is because it is out of touch with the realities of understanding, software and developers. The reality of understanding refers to the fact that SV systems present generic visualizations instead of visualizations for specific problems. The reality of software refers to SV addressing past problems and solutions instead of today's heterogeneous systems. The reality of developers refers to the cost of learning and implementing a SV tool in terms of time and effort. This echoes some of the reasons lecturers cite for not using SV tools in their teaching.

2.6.3 How successful is visualization

Feedback on the success of visualization is mixed. Despite lecturers' general perception, research shows that visualization is not always pedagogically effective or used effectively (Foutsitzis & Demetriadis, 2008; Hundhausen et al., 2002; Laakso, Rajala, Kaila & Salakoski, 2008a; Naps, Röβling et al., 2003; Pears, East et al., 2007; Shaffer et al., 2011; Shaffer et al., 2007). Shaffer et al. (2007:152) claim that the majority of visualizations appear to "have no pedagogical value" in the sense that "they give the user no understanding whatsoever of how the data structure or algorithm being visualized, works".

In a meta-study of 24 experimental studies to determine whether AVs are more effective than conventional teaching methods, Hundhausen et al. (2002:280) came to the conclusion that "*how* students use AV technology, rather than *what* students see, appears to have the greatest effect on educational effectiveness". The study suggests that "algorithm visualizations are educationally effective insofar as they enable students to construct their own understandings of algorithms through a process of active learning" (Hundhausen et al., 2002:282). Hundhausen et al. (2002) postulate that the educational effectiveness of an AV would be determined by the level to which students engage with the AV. This ties in with the learning theory of Cognitive Constructivism (Ben-Ari, 2001), whereby learners would construct their own knowledge of a specific algorithm by engaging with it.

2.6.3.1 Learner engagement with visualization technology

Following up on the meta-study by Hundhausen et al. (Hundhausen et al., 2002), and based on a review of experimental studies of visualization effectiveness, Naps, Röβling et al. (2003) defined the Engagement Taxonomy (ET) of six levels of learner engagement with visualization technology. This taxonomy is shown in Table 2.2. Their hypothesis is that higher levels of learner engagement produce more effective learning results.

Table 2.2 The Engagement Taxonomy (Naps, Röβling et al. 2003)

1. No viewing.	There is no visualization to be viewed
2. Viewing	The visualization is only looked at, without any other form of engagement. This is therefore a passive action, but required by all higher forms.
3. Responding	Learners use the visualization to answer questions, possibly followed by more viewing.
4. Changing	Learners modify the visualization, for example, by changing input values.
5. Constructing	Learners create new visualizations of the algorithm either manually or by using a PV or AV tool, without necessarily coding it.
6. Presenting	The visualization is presented for discussion and feedback to an audience.

Lauer (2008) refined both the viewing and constructing levels of the ET (Naps, Röβling et al., 2003) as described in Table 2.2 (Naps, Röβling et al., 2003). Viewing was subdivided into *passive viewing* and *active viewing*. In passive viewing learners have no control to rewind the animation and there are no fixed breakpoints after intermediate steps. In the category active viewing, users may return to earlier stages of the algorithm and/or stop the animation at break points provided, to better highlight intermediate steps. Similarly, the author subdivided the constructing category into *constructive simulation* and *code-based simulation* (Lauer, 2008). In the constructive simulation category, students construct an animation by simulating an algorithm on a re-defined visualization, while in the code-based simulation category they code the algorithms using a visual tool. Based on the results of several other studies that investigated the relationship between learning result and levels of engagement, Lauer (2008) concludes that active viewing is on a higher level than passive viewing, and that changing and constructive simulation fits into the same level (level 4 in the ET (Naps, Röβling et al., 2003)), while code-based construction is on a higher level.

Both the ET (Naps, Röβling et al., 2003) and Lauer's (2008) refinement thereof are based on work in AV research and the types of engagement found in AV tools. This research report's focus is on PV. Since PV tools support other types of engagement, Myller, Bednarik, Sutinen and Ben-Ari (2009) extended the ET for PV. In particular, PV tools may provide opportunities to offer interactive input and modify the source code used for the visualization. The extended ET is shown in Table 2.3 below. Levels marked with an asterisk (*) are from the original ET, although some definitions were adapted slightly. *Changing* has been divided into two categories, *changing* and *modifying*. Three new categories have been added, namely *controlled viewing*, *entering input*, and *reviewing*. Some of these correspond to some extent with Lauer's (2008) refinement in that *controlled viewing* is similar to *active viewing*, *constructing* to *constructive modification*, and *modifying* to *constructive simulation*.

Table 2.3 The Extended Engagement Taxonomy (Myller et al., 2009)

No viewing (*)	There is no visualization to be viewed, but only material in textual format. For example, the students are reviewing the source code without modifying it or they are looking at the learning materials.
Viewing (*)	The visualization is viewed with no interaction. For example, the students are looking at the visualization or the program output.
Controlled viewing	The visualization is viewed and the students control the visualization, for example by selecting objects to inspect or by changing the speed of the animation.
Entering input	The student enters input to a program or parameters to a method before or during their execution.
Responding (*)	The visualization is accompanied by questions which are related to its content.
Changing (*)	Changing of the visualization is allowed during the visualization, for instance, by direct manipulation.
Modifying	Modification of the visualization is carried out before it is viewed, for example, by changing source code or an input set.
Constructing (*)	The visualization is created interactively by the student by construction from components such as text and geometric shapes.
Presenting (*)	Visualizations are presented and explained to others for feedback and discussion.
Reviewing	Visualizations are viewed for the purpose of providing comments, suggestions and feedback on the visualization itself or on the program or algorithm.

Sorva, Karavirta & Malmi (2013) produced a comprehensive survey of PV systems for teaching novices about the run-time behaviour of programs. To assist with this process they extended the taxonomies proposed by Naps, Röβling et al. (2003) and Myller et al. (2009), in two dimensions to reflect direct engagement with the visualization by the learner (vertical) and content ownership (horizontal). They call their taxonomy the 2DET Engagement Taxonomy.

Figure 2.2 shows the two dimensions in the 2DET taxonomy. *Direct Engagement* corresponds to a large degree with the taxonomies by Naps, Röβling et al. (2003) and Myller et al. (2009), while *Content Ownership* refers to the learner's relationship with the target software. Table 2.4 describes the categories in the 2DET. The categories in the 2DET taxonomy as shown in Table 2.4 are self-explanatory. However, it should be noted that the category *own content* on the *Content Ownership* dimension, refers to using a PV tool to examine a learner's own program, which differs from the *creating* level on the *Direct Engagement* level (Sorva, Karavirta & Malmi, 2013).

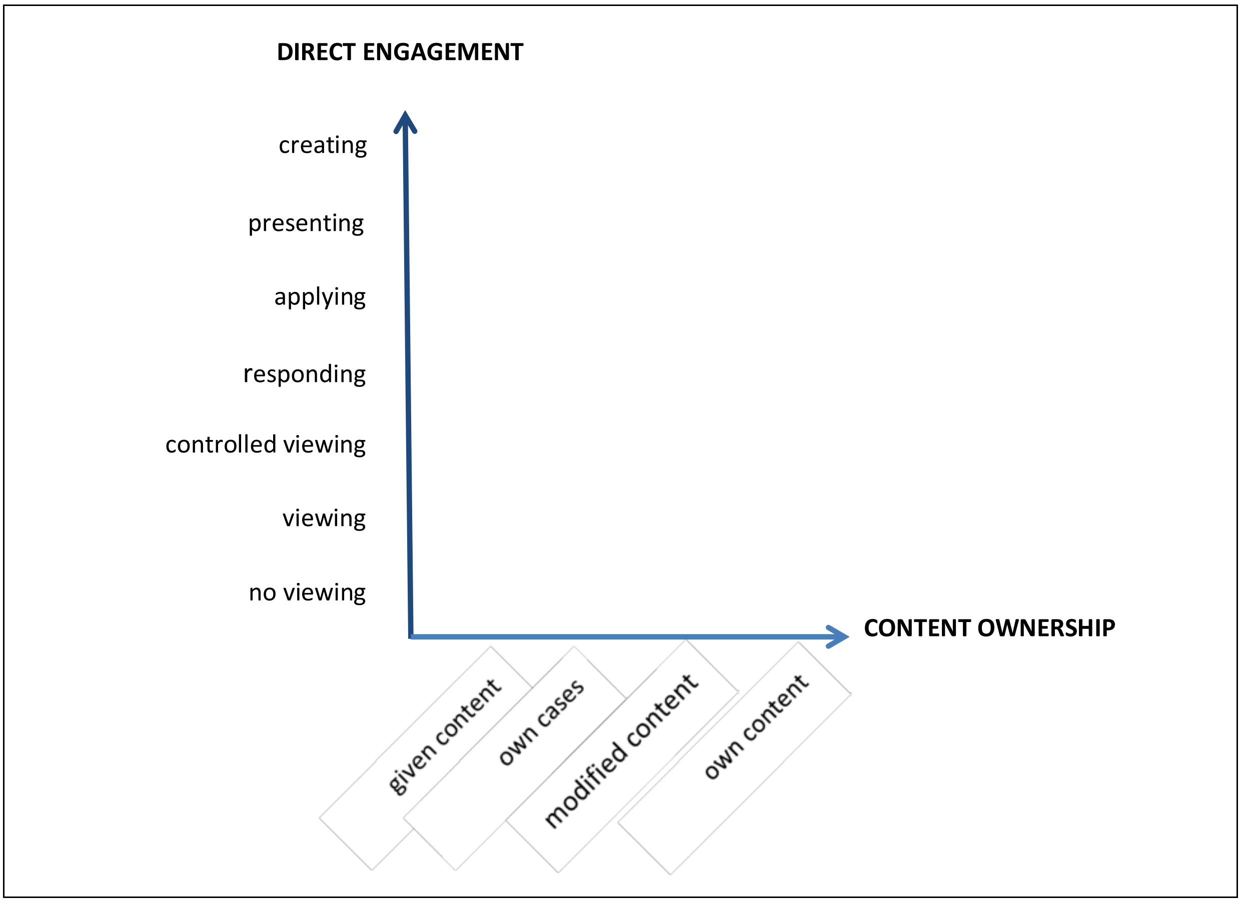


Figure 2.2 The two dimensions of the 2DET Taxonomy (Sorva, Karavirta & Malmi, 2013)

2.6.3.2 Research on the educational value of software visualization

Various program and algorithm visualizations (PAVs) have been developed over the years, but only a few studies could be found on the effectiveness and educational value of such tools (Kaila, Rajala, Laakso & Salakoski, 2010). A number of research efforts have been based on the ET (Naps, Röβling et al., 2003) and its extension (Myller et al., 2009). Myller et al. (2009) investigated the correlation between the ET and the impact of two visualization tools, Jeliot 3 and BlueJ, in a collaborative learning situation. They found that the levels of the ET taxonomy correlate positively with the amount of interaction, and that interaction is an important part of successful collaboration. Laakso, Myller and Korhonen (2009) also used the extended ET to investigate the difference between the *controlled viewing* and *changing* engagement levels in collaborative pair learning with the AV TRAKLA2 and confirmed that students on the *changing* engagement level learned more than those who engaged on the *controlled viewing* level.

Table 2.4 The categories of the 2DET Taxonomy (Sorva, Karavirta & Malmi, 2013)

		The direct engagement dimension
#	**Level**	**Description**
1	No viewing	The learner does not view a visualization at all.
2	Viewing	The learner views a visualization with little or no control over how he does it.
3	Controlled viewing	The learner controls how he views a visualization, either before or during the viewing, for example, by changing animation speed or choosing which images or visual elements to examine.
4	Responding	The learner responds to questions about the target software, either while or after viewing a visualization of it.
5	Applying	The learner makes use of or modifies given visual components to perform some task, for example, direct manipulation of the visualization's components.
6	Presenting	The learner uses the visualization in order to present to others a detailed analysis or description of the visualization and/or the target software.
7	Creating	The learner creates a novel way to visualize the target software, for example, by drawing or programming or by combining given graphical primitives.
		The content ownership dimension
#	**Level**	**Description**
1	Given content	The learner studies given software whose behaviour is predefined.
2	Own cases	The learner studies given software but defines its input or other parameters either before or during execution
3	Modified content	The learner studies given software that they can modify or have already modified.
4	Own content	The learner studies software that they created themselves.

While Lauer (2006) found no difference in performance of students who interacted with an AV on three different levels, namely *viewing*, *changing* and *constructing*, other research efforts confirm that higher levels of engagement in the active engagement category leads to better learning results (Ben-Ari et al., 2011; Grissom, McNally & Naps, 2003; Isohanni & Knobelsdorf, 2011; Kaila et al., 2009; Urquiza-Fuentes & Velázquez-Iturbide, 2009a). In particular, Urquiza-Fuentes and Velázquez-Iturbide (2009b) did a survey of 18 PAVs that reported success in 33 evaluations. Nine of them were only evaluated for usability, while the others were evaluated for their educational effectiveness. Three of these were PVs – Jeliot (Ben-Ari et al., 2011), VIP (Virtanen et al., 2005) and WinHIPE (Urquiza-Fuentes & Velázquez-Iturbide, 2007). They found that PAV can enhance learning with respect to knowledge acquisition at any engagement level above the *no viewing* level; attitude can be improved from the *responding* level upwards; and programming skills at the *changing* and *presenting* levels. To improve the effect of visualizations they recommend additional text or narrative content and explanations, providing feedback on students' actions, extra time to use PAVs and a student-centred approach in the design of PAV construction kits. Advanced features such as different execution scenarios, integration with an IDE or an interface to manipulate animations may improve learning outcomes. The usability of a PAV also plays an important role. Evaluating the PV ViLLE using the ET, Kaila et al. (2009) also found ViLLE to be especially useful for novices if used in an engagement level higher than viewing

Urquiza-Fuentes and Velázquez-Iturbide reported in three papers (Urquiza-Fuentes & Velázquez-Iturbide, 2012a; Urquiza-Fuentes & Velázquez-Iturbide, 2012b; Urquiza-Fuentes & Velázquez-Iturbide, 2013) on a follow-up study on the effectiveness of the level of engagement using an existing IDE with visualization features, WinHIPE. They found that engagement on both the viewing and constructing level improved the grades and lowered the drop-out rates of students, in comparison with the control group that did not use animation. Moreover, they found that for simple topics the traditional approach (without animation) is sufficient, but that the traditional approach and viewing outperformed constructing in highly complex topics. The determining factor in highly complex topics appears to be the instructor's explanations, either verbally in class or textually integrated in the animation.

Research on educational effectiveness of PVs without using the ET (Naps, Röβling et al., 2003) on UUhistle and BlueJ confirms the importance of engagement. When the educational effectiveness of ViLLE was evaluated without the ET, the results also indicated that it might have a positive effect (Rajala, Laakso, Kaila & Salakoski, 2008). Sorva, Lönnberg and Malmi (2013) did a qualitative empirical evaluation of the visual program simulation (VPS) system UUhistle without using the ET. VPS is described as an interactive form of educational program visualization, in which learners use graphical controls to direct a program's execution instead of watching an animation of it. Once again the results indicate that the way in which the students use VPS, determines how much they benefit from it. However, Sorva, Karavirta and Malmi (2013) conclude in their survey of PV tools used in the teaching of introductory programming that although the results reported from evaluations are mostly positive, it is difficult to indicate the effectiveness of levels of engagement above controlled viewing.

When Lahtinen, Ahoniemi and Salo (2007) integrated the PV system VIP into their introductory course work and allowed students to choose voluntarily whether they use VIP or not in the weekly exercises, three groups were discerned: students who never used VIP, a quarter of the class who always used VIP, and a group who used it intermittently. Though the drop-out rate for the group who never used the PV was considerably higher than the group who consistently used PV, they could not conclude that the PV itself motivated the students to continue using it. However, students indicated that the more difficult a topic is, the more useful they find the visualization. Student feedback on ViLLE also confirmed that they found it useful (Kaila et al., 2009) and a course-long evaluation of ViLLE showed that it seems to be beneficial in tracing code as well as in developing program writing skills (Kaila et al., 2010). Prior experience of ViLLE also improved students' performance, indicating that familiarising students with the PV reduces the cognitive load of learning to use it (Laakso, Rajala, Kaila & Salakoski, 2008b).

Although students may indicate that they find visualizations useful, Sorva, Lönnberg and Malmi (2013) also found that students may have limited ways of understanding. Students might for example not always attribute meaning to the visual elements, or fail to associate the visualized concepts with programming practise. In order to address this, lecturers should assist students in understanding the visualization itself as well as the value of learning programming concepts with program visualization.

While active engagement is necessary to learn from PAV, an advanced tool might not be required for this engagement. In this regard, Hundhausen and Douglas (2000) found that students constructing their own low-fidelity AV with simple art materials, demonstrated the same level of understanding as students engaging with a pre-defined visualization in active viewing and changing input values for the AV. Bennedsen and Schulte (2010) evaluated the effect of a visual debugger to help students learning about object interaction in a controlled experiment, by using the debugger (similar to PV) and object inspector in BlueJ. The control group used BlueJ for showing the source code and manual tracing instead of the debugger. Although using the debugger improved the students' performance, it did not cause a statistically significant effect between the results of the experimental group and the control group. This finding cannot be ascribed to an inherent defect in BlueJ, since Kölling's (2008b) evaluation of BlueJ, based on surveys and anecdotal evidence as well as the widespread acceptance of BlueJ (in 2008 more than 800 universities used BlueJ), confirms its usability.

Hertz and Jump (2013) also report on the success of incorporating a pen-and-paper method of tracing, called a program memory trace, that depicts all of the program's accessible memory (heap, stack and static memory) in the trace area. Students in the trace-based teaching classes were no more willing to trace on their own than students in previous classes, where trace-based teaching was not used, but they were willing to use it to debug, and believed that it helped them to learn. Comparing the grades of students' from the three years preceding the change to trace-driven teaching, with that of the subsequent four years, shows that trace-based teaching leads to an improvement in course grades and a considerable reduction in failure and drop-out rates. It is interesting to note that the lab grades, an important reflection of programming skills, have at the same time improved considerably more than the course grades. Hertz and Jump (2013) argue that this indicates that the students' understanding have improved and that they have developed viable mental models.

In contrast, Salakoski, Korhonen, Qiu, Grandell, Laakso & Malmi (2005) found that students' results improved when the AV TRAKLA2 was introduced, in comparison to previous years when students only did pen-and-paper exercises. The students' attitude also improved and in their self-evaluations they indicated that the best learning results are achieved by combining traditional exercises with web-based exercises.

It is clear that engagement with a visualization, whether it is a PAV system or a manual visualization of a program by means of tracing, contributes to students' program comprehension. Therefore, much of the benefit a student derives from using a visualization will depend on their active engagement with it.

2.7 Summary and conclusion

This chapter provided the background for this study on the role of visualization to enhance comprehension in ODL programming education at Unisa. The visualization takes the form of tracing, and the study investigates its effect in the introductory programming module COS1511. To this end, ODL, teaching programming in distance education, teaching introductory programming courses, tracing itself and visualization were considered in this chapter.

The nature of the ODL environment and specifically at Unisa has been described in section 2.2. Of note here is the ‘distance’ in ODL and factors at Unisa that influence the ‘distance’, which may have an effect on student performance. This includes the large number of students studying in their second language, the effect that the difference in infrastructure in rural and urban areas has on the level of exposure to and availability of modern technology with the resulting effect on student support, and the poor preparation for higher education among Unisa students, which may include inadequate listening and reading skills.

Section 2.3 provided an overview of teaching approaches and using visualizations in distance education in general. In many instances this does not differ significantly from face-to-face teaching.

Section 2.4 focused on teaching introductory programming courses. The pedagogy of the three main approaches namely teaching programming as an application of skills in problem solving; learning a particular programming language; and code/system production, were described. Teaching programming strategies as an alternative approach has also been discussed. Some recommendations for a conventionally structured course where the focus is on learning a particular programming language were offered. Unisa’s approach for the COS1511 modules, used in this study, is an imperative-first approach teaching C++ as a basis for follow-up object-oriented courses.

Section 2.4 also covered the role of mental models; threshold concepts and the LEM effect in learning to program. Students need to develop mental models of several aspects when learning to program. This includes mental models of the programming language; the computer as a ‘notional machine’; the problem domain or task the program should accomplish; the intended program and the program as it actually is. Threshold concepts are difficult core concepts that could hinder students learning, while the LEM effect postulates that the effect of successful or unsuccessful learning has momentum, which would either make it easier or more difficult to learn new concepts.

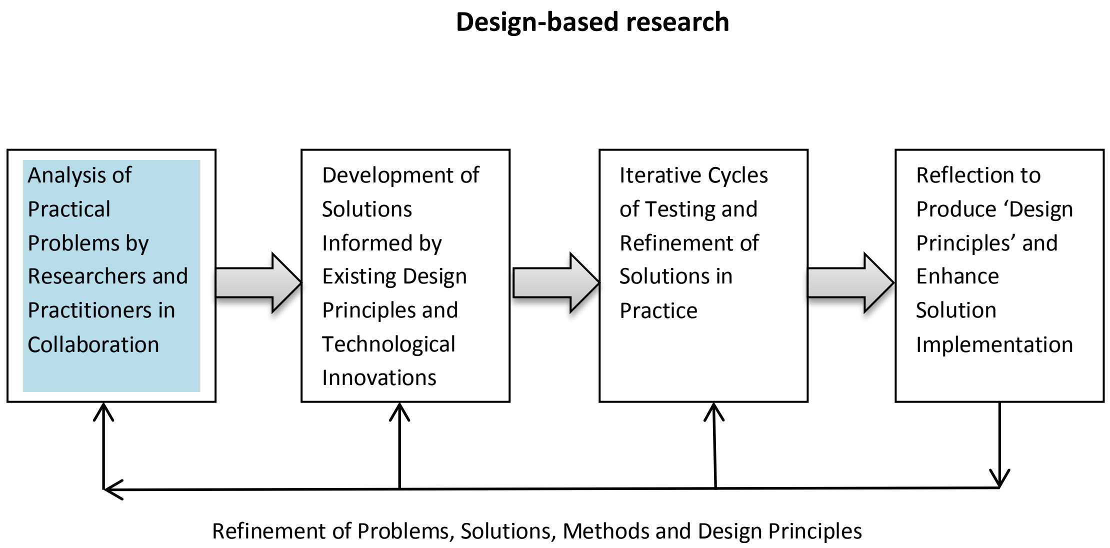
Lastly, section 2.4 addressed the problems novices experience by investigating the difference between novices and experts and considering specific aspects of programming and programming concepts novices find difficult. Experts have well-developed and organised mental models which they know how to combine as well as sophisticated problem-solving skills that they apply in planning and debugging their programs. Novices in contrast, frequently have fragile programming specific knowledge, experience difficulty in planning programs, and lack efficient debugging skills. In addition, they have a variety of misconceptions, many of which relate to lack of a viable mental model of the 'notional machine', from misconceptions on assignment and the execution sequence of a program, to misconception on objects, pointers and memory topics. The added complexity of OO may increase these problems.

Section 2.5 considered tracing, one of the methods that can assist with clearing up misconceptions and developing mental models. Tracing is defined as tracking code with the actual values of variables – 'concrete simulation' and on a higher level, 'symbolic tracing' that simulates the steps in program execution. Tracing plays an important role in program comprehension since it helps to construct a model of the program's purpose. It is also an important debugging strategy. Furthermore, research has shown that novices first have to master tracing, that is reading code, before they develop the ability to explain and write code. Novices find tracing difficult because it is a mentally demanding activity that requires understanding of programming language constructs and control flow. They also have difficulty in drawing and using diagrams that track program state. However, research has shown that teaching tracing skills as an integral part of a programming course can produce positive results.

In section 2.6, visualization was covered with an overview of SV and the various tools available to introductory programming courses. This study focuses on PV systems that visualize the execution of a program step by step, similar to tracing a program. AV is related to PV and visualizes the execution of an algorithm, but on a higher level than PV. Reports on the success of SV are mixed. The level of learner engagement plays a key role in the success of SV in education. Engagement on the higher levels of Naps' (2003) ET where learners have more active engagement with visualization, leads to better learning results. However, it may not be necessary to use a sophisticated tool to engage learners with visualization. Some research has shown that pen-and-paper activities to engage learners in tracing programs are also effective.

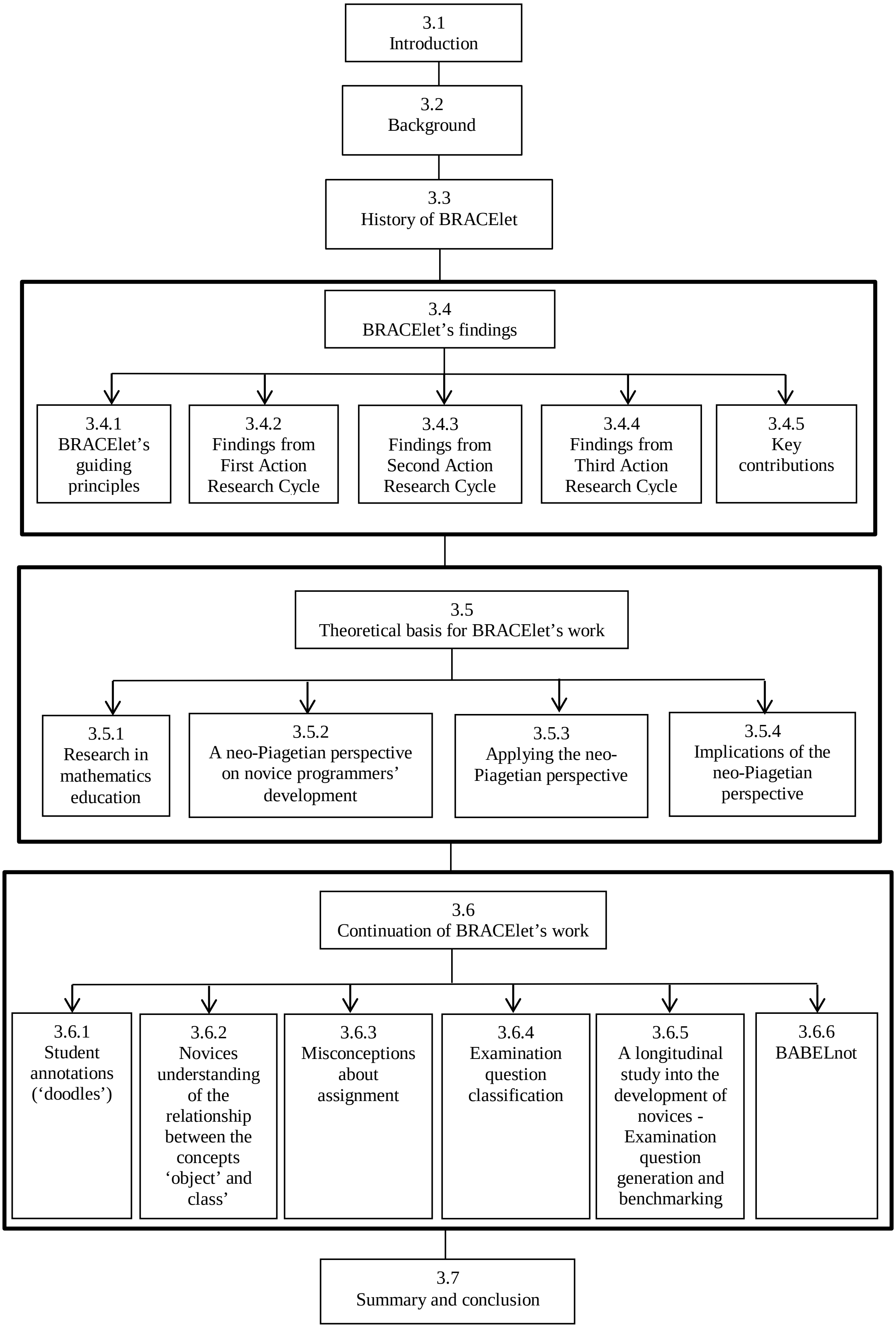
As mentioned before the BRACElet project (Clear et al., 2009; Lister et al., 2004; Lister et al., 2010; Whalley & Lister, 2009) provides the basis for this study. The next chapter discusses the contribution of the BRACElet project in understanding how novices learn to program and the role tracing in particular plays in that process.

Design-based research phase covered in Chapter 3


Design-based research
Analysis of Practical Problems by Researchers and Practitioners in Collaboration
Development of Solutions Informed by Existing Design Principles and Technological Innovations
Iterative Cycles of Testing and Refinement of Solutions in Practice
Reflection to Produce 'Design Principles' and Enhance Solution Implementation
Refinement of Problems, Solutions, Methods and Design Principles

Phase	**Element**	**Position**
Phase of design-based research (Reeves, 2006)	*Topics/elements that need to be addressed*	*Position in this thesis*
PHASE 1: Analysis of practical problems by researchers and practitioners in collaboration	Statement of problem	Chapter 1, Section 1.3.1 Chapter 4, Section 4.3.2.1
	Consultation with researchers and practitioners	Chapter 4, Section 4.3.2.1 and section 4.3.4.3
	Research questions	Chapter 1, Section 1.3.3 Chapter 4, Section 4.3.2.3
	Literature review	Chapters 2 and 3, Section 5.2
PHASE 2: Development of solutions informed by existing design principles and technological innovations	Theoretical framework	Chapter 5, Section 5.2
	Development of draft principles to guide the design of the intervention	Chapter 5, Section 5.3
	Description of proposed intervention	Chapter 5, Section 5.5
PHASE 3: Iterative cycles of testing and refinement of solutions in practice	Implementation of intervention (First iteration) Participants Data collection Data analysis	Chapter 6
	Implementation of intervention (Second and further iterations) Participants Data collection Data analysis	Chapter 7
PHASE 4: Reflection to produce 'design principles' and enhance solution implementation	Design principles	Chapters 5, 6 and 7
	Designed artefact(s)	Available on course website
	Professional development	Chapter 8

Map of Chapter 3 (The BRACElet Project)


3.1 Introduction
3.2 Background
3.3 History of BRACElet
3.4 BRACElet's findings
3.4.1 BRACElet's guiding principles
3.4.2 Findings from First Action Research Cycle
3.4.3 Findings from Second Action Research Cycle
3.4.4 Findings from Third Action Research Cycle
3.4.5 Key contributions
3.5 Theoretical basis for BRACElet's work
3.5.1 Research in mathematics education
3.5.2 A neo-Piagetian perspective on novice programmers' development
3.5.3 Applying the neo-Piagetian perspective
3.5.4 Implications of the neo-Piagetian perspective
3.6 Continuation of BRACElet's work
3.6.1 Student annotations ('doodles')
3.6.2 Novices understanding of the relationship between the concepts 'object' and class'
3.6.3 Misconceptions about assignment
3.6.4 Examination question classification
3.6.5 A longitudinal study into the development of novices - Examination question generation and benchmarking
3.6.6 BABELnot
3.7 Summary and conclusion

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Chapter 3 The BRACElet Project

3.1 Introduction

In this chapter the researcher continues to provide a context for the research by providing an overview of the BRACElet project (Clear et al., 2009; Lister et al., 2004; Lister et al., 2010; Whalley & Lister, 2009) that served as the basis for this study, as indicated in Chapter 2. The focus is on the contribution made by the BRACElet project in understanding how novices learn to program, the theoretical foundation underlying the process of learning to program and the role of tracing in that process. This provided the motivation for developing the tutorial to teach students how to trace.

Section 3.2 provides the background of the studies that motivated the BRACElet project, while in section 3.3 the history of BRACElet is reviewed. In section 3.4, BRACElet's guiding principles are described before BRACElet's findings are presented. In section 3.5 two possible interpretations are discussed as a theoretical foundation for BRACElet's work, namely research in mathematical education and a neo-Piagetian perspective. The neo-Piagetian perspective is then applied to some of the results of the BRACElet project and the implications of this perspective on teaching and learning of programming considered. Section 3.6 consists of some of the extensions of BRACElet's work, with the summary and the conclusion in section 3.7.

3.2 Background

An important body of work on the research on how students learn to program was contributed by the BRACElet project. The BRACElet project originated in New Zealand in December 2004, with the final BRACElet workshop held in September 2010. It was a multi-institutional, multi-national computer education study investigating novice programmers' acquisition of programming skills. In particular, it considered a possible hierarchy in which novices learn to read, explain and write programs; and its exact order and its implications for the teaching and learning of programming (Clear et al., 2009; Lister et al., 2010; Whalley & Lister, 2009).

This project used mainly naturally occurring data in the form of examination responses from introductory computing courses (Lister et al., 2010). By July 2009, BRACElet had delivered more than thirty publications (co)written by more than twenty authors, mostly from New Zealand, Australia, and the USA (Lister et al., 2010). During the period September 2007 to February 2010, sixteen papers were published by 26 authors from seven different countries and 14 different institutions (Lister & Edwards, 2010). A considerable number of papers that either continued or diversified the work done in BRACElet, have also been published since the final workshop (see for example (Corney, Lister, Hogan, Fidge, Roggenkamp & Cardell-Oliver, 2012; Eckerdal, Laakso, Lopez & Sarkar, 2011; Lister, Corney, Curran, D'Souza, Fidge, Gluga, Hamilton, Harland, Hogan &

Kay, 2012; Murphy, Fitzgerald, Lister & McCauley, 2012; Sheard, Simon, Carbone, Chinn, Laakso, Clear, Raadt, D'Souza, Harland, Lister, Philpott & Warburton, 2011; Simon, 2011; Simon, Chinn, Raadt, Philpott, Sheard, Laakso, D'Souza, Skene, Carbone, Clear, Lister & Warburton, 2012).

BRACElet was inspired by the ‘Bootstrapping’ projects (Fincher, Lister, Clear, Robins, Tenenberg & Petre, 2005), namely Bootstrapping (2002), Scaffolding (2003) and BRACE[4] (2004). BRACElet built on the work of two ITiCSE working groups, the McCracken group (McCracken et al., 2001) and the Leeds group (Lister et al., 2004).

Bootstrapping (2002) was initiated by the US National Science Foundation with the aim of improving the state of Computer Science education (CS Ed) research in order to eventually improve the state of CS Ed itself. It took the form of an initial multi-institutional workshop introducing techniques and methodologies in CS Ed research, and presenting a shared research project. Participants then gathered data during the following year to share and analyse at a capstone workshop with the aim to report on those results in professional journals and also discuss continued collaboration. Scaffolding (2003) followed the same pattern, while BRACE (2004) was an Australasian CS Ed research project modelled on the same guidelines as the two US projects. Bootstrapping (2002) studied the manner in which novices construct programming concepts, while Scaffolding (2003) compared the way in which novices, graduating seniors and instructors design solutions. BRACE (2004) investigated cognitive, behavioural and attitudinal factors that might affect novice programmers’ success (Simon, Lister & Fincher, 2006).

The McCracken group (McCracken et al., 2001), a 2001 ITiCSE working group, investigated the programming ability of students at the end of their first one or two courses in computer science. As mentioned in section 2.4.2, they presented the following framework of learning objectives to describe the problem-solving skills first-year computing students should acquire:

- Abstract a problem from its description.
- Generate sub-problems.
- Transform sub-problems into sub-solutions.
- Re-compose the sub-problems into a working program.
- Evaluate and iterate.

The McCracken group used a short, lab-based assignment to assess a combined sample of 216 students from four universities on these learning objectives. The assessment involved a general evaluation (on program execution, verification, validation and style) and a degree of closeness score rating how close a student’s program is to a working solution. They also administered a student questionnaire. Quantitative analysis of the results shows a bimodal distribution, as well as a much worse student performance than expected, at all four universities. Qualitative analysis indicates that

[4] Building Research in Australasian Computing Education

the problems students experience with programming skills appear to be independent of country and educational system. Abstracting the problem from its description was identified as the most difficult part of problem-solving. The McCracken group ascribed the students' inability to program at the end of their first course to their lack of problem-solving skills and recommended further research on the assessment of programming skills among a broader base of computer science educators and universities.

The Leeds group (Lister et al., 2004) studied an alternative explanation for the poor results, namely that many students have a fragile grasp of basic programming principles as well as a lack of basic skills, such as tracing (manually executing) code. They argue that some minimal grasp of programming concepts and associated skills is necessary before a student can problem-solve in the manner defined by the McCracken group. Students from seven countries were tested on their comprehension of existing code. A set of twelve multiple choice questions (MCQs) was used. Students had to predict the outcome of executing a short piece of code ('fixed-code questions'), and also, when provided with the required function of a near-complete piece of code, to select the correct completion of the code from a small set of possibilities ('skeleton code'). While 941 students partook, only the data from 556 who completed all twelve questions were analysed. A total of 37 students were also interviewed and 56 doodles (scratch paper on which students worked while doing the MQCs) were examined. The data indicated that students find 'skeleton code' more difficult than 'fixed-code questions'. The Leeds group concluded that many students lack the knowledge and skills which are precursors to the problem-solving skills identified by the McCracken group, in particular the ability to read code.

In summary, of the studies that motivated the BRACElet project, the McCracken group (McCracken et al., 2001) investigated whether novices can write code, while Bootstrapping (2002) focused on how they understand programming constructs. Scaffolding (2003) examined how novices understand design and BRACE (2004) studied factors impacting on their programming ability and performance. The Leeds group (Lister et al., 2004) investigated novices' ability to read and trace code (Simon et al., 2006). BRACElet, in turn, studied novices' acquisition of programming skills to determine whether a hierarchy exists according to which novices learn to read, explain and write program code, as well as its implications for teaching and learning of programming.

3.3 History of BRACElet

Though not initially planned, the BRACElet[5] organisers soon began to understand the project's operation in terms of action research. Action research is frequently implemented as a cycle of *plan*, *act*, *observe* and *reflect* (De Villiers, 2005; Zuber-Skerrit, 1992). The first action research cycle built

[5] The name BRACElet reflects its continuation of the BRACE project (Lister et al., 2012)

theory about novices' acquisition of programming skills in terms of the taxonomies of Bloom and the Structure of the Observed Learning Outcome (SOLO) (Biggs & Kollis, 1982), while the second action research cycle investigated the relationship between code reading and code writing (Clear, Edwards, Lister, Simon, Thompson & Whalley, 2008). The third action research cycle continued investigating statistical relationships between reading and writing code, as well as whether programming consists of a hierarchy of knowledge and skills (Whalley & Lister, 2009).

The participants in the first BRACElet workshop, held in December 2004 in New Zealand, considered the work of the Leeds Group to lack a base of learning theories or educational models. Consequently, on reflection, they devised an instrument in the form of a set of multiple choice and short answer questions (Whalley & Clear, 2007; Whalley & Lister, 2009), based on the revised Bloom's taxonomy (Anderson, Krathwohl, Airasian, Cruikshank, Mayer, Pintrich, Raths & Wittrock, 2001). These questions were included in the exams for the following semester at some of the participating New-Zealand institutions, and the data the data obtained were analysed at the second BRACElet workshop (Clear, Edwards et al., 2008; Clear et al., 2009; Whalley & Clear, 2007; Whalley & Lister, 2009; Whalley & Robbins, 2007).

During the second BRACElet workshop at the 18th NACCQ conference of New-Zealand in 2005, the SOLO taxonomy (Biggs & Kollis, 1982) was introduced and consolidated as part of a toolkit for research at the partaking institutions. This was an attempt to gain a better understanding of the students' responses to the levels of difficulty of the multiple choice and short-answer questions (Clear, Edwards et al., 2008; Clear et al., 2009; Whalley & Lister, 2009; Whalley & Robbins, 2007). The results were published in several papers (Lister et al., 2006; Philpott et al., 2007; Thompson, Luxton-Reilly, Whalley, Hu & Robbins, 2008; Thompson, Whalley, Lister & Simon, 2006; Whalley, 2006; Whalley, Lister, Thompson, Clear, Robbins, Kumar & Prasad, 2006). See the next section on BRACElet's findings for a discussion of the results.

At the third BRACElet workshop in March 2006, at Auckland University of Technology (AUT) in Auckland, Australia, a common 'prototype' framework was developed to allow participants flexibility in their research as well as to compare and contrast experiments. Three essential components were included (Clear, Ewards et al., 2008; Clear et al., 2009; Whalley & Clear, 2007; Whalley & Robbins, 2007), namely –

- a reading and tracing component to measure students' ability to read and understand code, using Bloom's taxonomy to judge the difficulty;
- a SOLO component to classify a student's ability to abstract, typically with a question to 'explain in plain English'; and
- a writing component where students write some code comparable in difficulty to one of the reading questions.

During the fourth workshop at the 19th annual NACCQ conference in Welllington, New-Zealand, in July 2006, the common framework developed at the third workshop was reviewed and extended to further investigate the writing skills of novice programmers. The framework now included four components (Clear et al., 2009; Whalley & Robbins, 2007) namely –

- Bloom’s taxonomy to categorise the cognitive process required to answer a question;
- the SOLO taxonomy to classify the reasoning level expressed in answers;
- a categorization of the question-types used in BRACElet; and
- analysis of student script annotations to provide insight into the processes students follow to solve a problem.

Both the fifth and sixth workshops were used to reflect and plan for the second action research cycle. During the fifth workshop at the 20th annual NACCQ conference in Nelson, New-Zealand, in July 2007, questions fitting the common BRACElet framework were set (Clear et al., 2009). A new type of question, Parsons’ problems (Parsons & Haden, 2006), was included. Parsons’ problems consist of jumbled code which should be placed in the correct order. The sixth workshop at AUT, Auckland, Australia, in December 2007, was sponsored by the ACM and SIGCSE and attended by nine institutions. Contributed data were analysed to develop new research instruments to allow the evaluation of novices’ program-writing skills in order to investigate a correlation with their program-reading skills (Clear, Edwards et al., 2008; Clear et al., 2009).

The seventh workshop in January 2008, at the ACE2008 conference in Wollongong, Australia, initiated the action for the second BRACElet action research cycle. The goals for this action research cycle were to consolidate ‘explain in plain English’ questions; generate new questions; relate answers to SOLO levels; examine gender effects, as well as differences between international and local students, and undergraduate and postgraduate students; and to develop an ideal examination paper (Clear, Edwards et al., 2008; Clear et al., 2009).

At the eighth workshop in July 2008, at the NACCQ conference at AUT, Auckland, Australia, analysis of the assessment data from novice programmers contributed by participating institutions, resulted in further refinement of the reading and writing classifications in the SOLO taxonomy (Clear et al., 2009).

The ninth BRACElet workshop at ICER in Sydney, in September 2008, was used to reflect on the data analysis up to that point, and for preliminary discussions on the third action research cycle (Clear et al., 2009; Whalley & Lister, 2009). BRACElet regarded code writing ability as the dependent variable in their investigation into a hierarchy of knowledge and skills in programming, as code writing is considered to be at the top of the hierarchy. The third action research cycle continued searching for statistical relationships between code writing and the other skills considered to be pre-cursors to code writing (Whalley & Lister, 2009).

At the tenth BRACElet workshop in Wellington, New-Zealand, during the ACE2009 conference in January 2009, the BRACElet 2009.1 (Wellington) Specification was issued. This Specification published the research plan for the third BRACElet action research cycle and invited new participants to join (Clear et al., 2009; Whalley & Lister, 2009). The common core of the BRACElet 2009.1 (Wellington) Specification consists of three parts, Basic Knowledge and Skills; Reading/Understanding; and Writing. The Basic Knowledge and Skills part should test all the programming constructs used in the other two parts to establish whether students understand the programming constructs and have mastered relatively concrete skills such as tracing. The Reading/Understanding part should determine whether students can recognize the purpose of a piece of code from reading the code (that is, are they able to abstract?). At least one of the following types of questions should be used here: ‘Explain in plain English’; Parson’s problems or Code Classification Questions (placing pieces of code into two groups so that the code pieces in a group are similar in some way, and different from the code pieces in the other group). For the Writing part, at least one code writing task should be of similar complexity to one of the tracing tasks, and likewise, at least one code writing task should be of comparable complexity as a Reading/Understanding part (Clear et al., 2009; Whalley & Lister, 2009).

The eleventh BRACElet workshop was held at ITiCSE in Paris in July 2009. The group that attended this workshop, replicated earlier BRACElet studies at other institutions to include a far larger pool of naturally occurring data; refined the SOLO-taxonomy for code-explaining questions; extended the SOLO taxonomy to cover code-writing questions; expanded earlier studies on student annotations (‘doodles’) while answering examination questions; and explored a theoretical base in mathematics education for the graduated hierarchy of skills development in programming. This confirmed earlier empirical evidence about the relationship between code explaining and code writing, although the exact nature of the relationship remains unclear (Clear et al., 2011; Lister et al., 2010; Lister & Edwards, 2010).

The twelfth BRACElet workshop was held in Brisbane during January 2010 at the ACE2010 conference. A number of BRACElet activities (or ‘threads’) for the following year were presented (Clear et al., 2011; Lister & Edwards, 2010). Two of these are incorporated in the BABELnot project (Lister et al., 2012) that continues BRACElet’s work, namely –

- a survey and analysis of the types of exam questions used in examination papers for novice programmers, including interviews with academics on how it is done; and
- an analysis of longitudinal data for students from the introductory course to the final capstone project.

The final BRACElet workshop was held in September 2010, at the AUT, with a two-fold purpose, namely to extend the work on theory that began in Paris in 2009; and to launch an on-going research programme into the development from novice to professional programmer (the 'NExpertise' project). The workshop divided into three groups that focused on the following issues (Clear et al., 2011):

- Investigating a hierarchy in the development of novices' understanding of the relationship between the concepts 'object' and 'class'.
- An investigation into novices' misconceptions about assignment.
- A longitudinal study on individual students to determine whether exam results in introductory programming courses can predict success.

As can be seen from the above and mentioned before (see section 3.2) BRACElet conducted an extensive multi-institutional, multi-national study into novices' acquisition of programming skills over three action-research cycles. The first four BRACElet workshops constituted the first action research cycle, while the fifth to the eighth workshops covered the second action research cycle (Clear, Edwards et al., 2008), and the ninth to the thirteenth workshops the third cycle (Clear et al., 2011). The most important BRACElet findings are discussed in the next section.

3.4 BRACElet's findings

As described in sections 3.2 and 3.3, BRACElet investigated a possible hierarchy in which novices learn to read, explain and write programs, and if so, the exact order thereof, with the resulting implications for the teaching and learning of programming (Clear et al., 2009; Lister et al., 2010; Whalley & Lister, 2009). Furthermore, BRACElet used a form of action research which mainly analyses naturally occurring data in the form of examination responses from introductory computing courses according to the Bloom and SOLO taxonomies (Lister et al., 2010). BRACElet's guiding principles, including their adaptation of Bloom's taxonomy for computer science assessment, as well as the SOLO taxonomy, are described first, before the findings from the three action research cycles are discussed. Finally their key contributions are presented.

3.4.1 BRACElet's guiding principles

BRACElet's guiding principles included the following (Clear, Edwards et al., 2008; Whalley & Clear, 2007; Whalley & Lister, 2009; Whalley & Robbins, 2007):

- A strong belief in a teaching-research nexus in which the research informs and improves teaching – typical of educational action research.
- That student assessment are always more important so that the research is not allowed to compromise the course.
- A common core or framework comprising a minimal set of properties that must be used in all examinations.

- Repetition at different institutions and in different formats to confirm research outcomes.
- A set of rules of engagement about the research process itself.
- A publication protocol,
- Requirements for joining BRACElet, such as obtaining ethical clearance from their institution.

Both the revised Bloom's taxonomy (Anderson et al., 2001) and the SOLO taxonomy (Biggs & Kollis, 1982) were used in BRACElet's research. In the following two sub-sections these taxonomies are described.

3.4.1.1 Bloom's taxonomy for computer science assessment

In the common framework used in BRACElet's research, the revised Bloom's taxonomy (Anderson et al., 2001) was used to categorise the cognitive processes required to answer a question. To this end, Thompson et al. (2008) adapted Bloom's taxonomy for computer science assessment in introductory programming courses.

Bloom's taxonomy is a hierarchy of six categories, that is remember, understand, apply, analyse, evaluate and create (Anderson et al., 2001). Thompson et al. (2008) adapted these categories as follows:

- **Remember** is defined as retrieving relevant knowledge from long-term memory, a process that includes recognising and recalling (Anderson et al., 2001). In programming assessment Thompson et al. (2008) interpret this as –
  - identifying a construct in a program segment;
  - recognising the implementation of a subject area concept;
  - recognising an appropriate description for a subject area concept or term; and
  - recalling material explicitly covered in the course.
- **Understand** means to determine the meaning of instructional messages, that include oral, written and graphical communication (Anderson et al., 2001). Thompson et al. (2008) interpret this to –
  - translate an algorithm from one form of representation to another (for example to translate an algorithm in pseudo code into a programming language);
  - explain a concept, algorithm or design pattern; and
  - present an example of a concept, algorithm or design pattern.
- **Apply** is defined as executing or using a procedure in a given situation (Anderson et al., 2001). Thompson et al. (2008) interpret this to –
  - apply a known process, algorithm or design pattern to a familiar problem that has not been solved previously in the same context, with the same data or with the same tools; and

  - apply a known process and algorithm or design pattern to an unfamiliar problem.
- **Analyse** is defined as dividing material into the parts that it is comprised of and detecting how the parts relate to one another and to an overall purpose or structure (Anderson et al., 2001). Thompson et al. (2008) interpret this as –
  - breaking up a programming task into its components such as classes or methods;
  - organising component parts to achieve an objective;
  - identifying critical elements of a development; and
  - identifying unimportant requirements or elements.
- **Evaluate** is defined as judging based on criteria and standards (Anderson et al., 2001). Thompson et al. (2008) interpret this as to –
  - determine whether a piece of code comply with requirements by defining an appropriate testing strategy; and
  - critique a piece of code based on coding standards or performance criteria.
- **Create** is defined as combining elements to form a coherent or functional unit; or reorganising elements to form a new pattern or structure (Anderson et al., 2001). Thompson et al. (2008) interpret this as –
  - producing a new alternative algorithm or a new combination of algorithms to solve a problem; and
  - constructing a code segment or program by inventing a new algorithm or applying known algorithms in a new (to the students) combination.

Note that to effectively analyse a question requires an in-depth knowledge of the course as a whole (Thompson et al., 2008).

3.4.1.2 The SOLO taxonomy

The BRACElet project used the SOLO taxonomy (Biggs & Kollis, 1982) to classify the reasoning level expressed in students' answers. The SOLO taxonomy describes the quality of a student's understanding of a topic through four levels, from the lowest and least sophisticated level, 'pre-structural', to the highest level, 'extended abstract' (Lister & Edwards, 2010). Using the revised Bloom's taxonomy (Anderson et al., 2001) produced mixed results, while the SOLO taxonomy could be applied more consistently (Clear, Whalley, Lister, Carbone, Hu, Sheard, Simon & Thompson, 2008; Sheard et al., 2008; Whalley et al., 2006).

BRACElet adapted the SOLO taxonomy to classify student responses on code-explaining questions as expounded in Table 3.1 (Clear, Whalley et al., 2008). At the lowest level, prestructural, the response is unrelated to the question or substantially lacks knowledge of programming constructs. On the next level, unistructural, a description for one portion of code is provided. A multistructural response provides a line by line description of code, while a relational response provides a summary of the code's purpose.

Table 3.1 The SOLO taxonomy for classifying responses on code-explaining questions (Clear, Whalley, Lister, Carbone, Hu, Sheard, Simon & Thompson, 2008)

SOLO category	Description
Relational [R]	Provides a summary of what the code does in terms of the code's purpose.
Multistructural [M]	A line by line description is provided of all the code.
Unistructural [U]	Provides a description for one portion of the code.
Prestructural [P]	Substantially lacks knowledge of programming constructs or is unrelated to the question

Based on the SOLO taxonomy, it was found that when students have to explain a code fragment, they frequently are able to explain what each line of code does (a multi-structural response), but are unable to describe the purpose of the code (a relational level response). Furthermore, students who cannot express a relational response, are usually unable to write coherent programs (Lister & Edwards, 2010).

At the eleventh BRACElet workshop in 2009, the SOLO taxonomy was also adapted to classify student responses to code-writing questions (Whalley, Clear, Robbins & Thompson, 2011). Biggs and Collis (1982) divided the SOLO categories in to two learning phases, an initial 'quantitative' phase and a subsequent 'qualitative' phase, which are also shown in the SOLO taxonomy as adapted by Whalley et al. (2011) in Table 3.2. During the quantitative phase students operate on the prestructural, unistructural and multistructural levels when writing code, while they operate on the relational and extended abstract levels in the qualitative phase. The unistructural level represents a direct translation of the specifications, while the multistructural level is on a slightly higher level with possible

Table 3.2 SOLO categories for code writing solutions (Whalley et al., 2011)

Phase	SOLO category	Description
Qualitative	Extended Abstract – Extending [EA]	Uses constructs and concepts beyond those required in the exercise to provide an improved solution.
	Relational – Encompassing [R]	Provides a valid well-structured program that removes all redundancy and has a clear logical structure. The specifications have been integrated to form a logical whole.
Quantitative	Multistructural – Refinement [M]	Represents a translation that is close to a direct translation. The code may have been reordered to make a valid solution.
	Unistructural – Direct Translation [U]	Represents a direct translation of the specifications. The code will be in the sequence of the specifications.
	Prestructural [P]	Substantially lacks knowledge of programming constructs or is unrelated to the question.

reordering of the specifications. At the relational level the specifications have been integrated to form a logical whole, while on the extended abstract level concepts and constructs beyond those required by the problem statement are used to provide an improved solution.

3.4.2 Findings from First Action Research Cycle

As mentioned in section 3.3., BRACElet's first action research cycle built theory about novices' acquisition of programming skills in terms of the Bloom's and SOLO (Biggs & Kollis, 1982) taxonomies as described above. They found that assessing programming fairly and consistently is complex and challenging. Educators may underestimate the cognitive difficulty of their assessment instruments, as well as the stages and time students require to develop programming skills. Furthermore, students who cannot read and summarise a short piece of code (classified as 'relational thinking' on the SOLO taxonomy), have not acquired enough skill to write their own code (Lister et al., 2006; Whalley et al., 2006). Weaker students do not naturally develop the ability to reason about code at an abstract level to determine its purpose (Lister, 2007; Lister et al., 2006). Philpott et al. (2007) identified a clear link between the ability to trace code and relational thinking on the SOLO taxonomy, and conclude that complete mastery of code tracing seems to indicate that relational thinking can be achieved. A less than 50% performance on tracing seems to indicate an inability to achieve relational thinking.

Whalley (2006) found that the different programming languages used in introductory programming courses had no effect on student performance. She used the revised Bloom's taxonomy (Anderson et al., 2001) in her investigation, and recommended that it be refined to accurately identify the difficulty of programming ideas and processes. Thompson et al. (2008) subsequently provided an interpretation of the revised Bloom's taxonomy (Anderson et al., 2001) for computer science, with the aim to foster a common understanding of the cognitive processes that programming requires and to enable discussion around assessment and cognitive processes.

Thompson et al. (2006), by using the SOLO taxonomy, compared a code classification question with an 'explain in plain English' question to determine students' ability to read and comprehend code. The classification question consisted of four short pieces of code which had to be classified into two groups according to similarities between the code pieces which were grouped together. Despite the fact that only 75% of the students attempted the classification question, they nevertheless concluded that this type of question is also a reasonably reliable indication of a student's ability to comprehend code.

Whalley, Prasad and Kumar (2007) analysed student script annotations ('doodles') with the SOLO classification in an attempt to gain insight into the processes students follow to solve a problem. There seemed to be no relation between the level of reasoning and the use of annotations by novice student programmers, but it confirmed three key findings from the Leeds group (Lister et al., 2004), namely that doodles tend to help students to reach the correct answer, higher achievers are inclined to doodle more and that students are more likely to trace fixed code questions than skeleton code questions.

In summary, BRACElet's first action research cycle used the revised Bloom's and SOLO taxonomies to develop a cognitive framework that can be used to classify the levels of difficulty of tasks used in their research (Thompson et al., 2008; Whalley & Clear, 2007; Whalley & Robbins, 2007). The main findings from this cycle indicates that students find tasks from the higher levels of the framework (such as writing code) more difficult than those tasks at lower levels; that the ability to read a piece of code and explain it in relational terms, is a higher order skill (Lister et al., 2006); and that complete mastery of code tracing seems to be a requirement for relational thinking (Philpott et al., 2007).

3.4.3 Findings from Second Action Research Cycle

BRACElet's second action research cycle investigated the relationship between code reading and code writing (Clear, Edwards et al., 2008). The first action research cycle confirmed that students struggle to develop the ability to reason about code at an abstract level. This implies a need for teaching techniques that help students to see the relationships between the parts of a program, as well as for assessment techniques to test for that ability.

Clear, Whalley et al. (2008) analysed the reliability of the SOLO taxonomy to categorise student responses to 'explain in plain English' questions, derived an augmented set of SOLO categories for application to the programming domain (see section 3.4.1.2), and statistically confirmed its consistency. Sheard et al. (2008) used the SOLO taxonomy to classify written student responses in two exams on introductory programming courses, one for a class of undergraduates, the other for a class of postgraduates. They found a positive correlation between student performance on SOLO reading tasks and on code writing tasks, as well as a higher level of SOLO responses from the postgraduate students. They believe that this is the result of the postgraduate group having developed higher level thinking skills during their undergraduate degree.

In contrast, Simon, Lopez, Sutton and Clear (2009) analysed two data sets, one from a university and the other from a polytechnic in an attempt to confirm that novices need to be able to read program code before being able to write it, but failed to reach a definite conclusion.

Another tool used in the investigation into the relationship between code reading and code writing, was Parson's problems, also called Parson's puzzles (Parsons & Haden, 2006). In a Parson's problem students have to write code by selecting from provided code fragments or statements. Denny, Luxton-Reilly and Simon (2008) evaluated Parson's problems as a new type of examination question. A low correlation between code writing and tracing, as well as between Parson's problems and tracing, seems to indicate that code writing and Parson's problems require similar skills, while code tracing requires different skills. Parson's problems are easier and less subjective to mark than code writing questions, while allowing lecturers to isolate and identify misconceptions (for example about logic or syntax) more accurately.

Lopez et al. (2008) used stepwise regression to analyse responses in a Java end-of-semester examination to construct a possible hierarchy of programming-related skills. The points each student earned on the examination's code writing tasks were used as the dependent variable at the top of the hierarchy. The examination questions were placed in the following eight categories:

- Basic knowledge, for example knowledge of programming constructs and syntax errors.
- Data, namely knowledge of data types and operations on data types.
- Sequence, such as Parson's problems, where students have to order code to solve a task.
- Tracing 1, non-iterative tracing tasks.
- Tracing 2, iterative tracing tasks.
- Exceptions.
- Explaining code.
- Writing code for a given problem.

Lopez et al. (2008) used a polytomous Rasch model (Rasch, 1993) to pre-process their data to address some of the non-linearities in grading. They found confirmation for an association between code tracing and code writing skills, especially for tracing loops, as well as an association between code reading and code writing skills. Other observations made with regard to a possible hierarchy, are that knowledge of basic programming constructs (basic knowledge and data) appears at the bottom of the hierarchy, consistent with what is expected. The authors did not find a statistically significant relationship between Tracing 1 (non-iterative) and Tracing 2 (iterative), but speculate that the Tracing 1 tasks might have been too simple (Lopez et al., 2008). The variable for Sequence tasks appeared lower in the path diagram than Tracing 2, which might have been caused by a too easy Parson's problem. Philpott et al.'s (2007) conjecture that mastery of code tracing is an essential requirement for relational thinking (explaining) is confirmed. Parson's problems, Tracing and Explain are intermediate skills, also consistent with previous BRACElet findings. Lopez et al. (2008) conclude that possibly programming-related skills do not form a strict hierarchy, but that skills from more than one lower level may influence the execution of a skill at a higher level in the hierarchy.

The second action research cycle confirmed a relationship between code tracing and code writing, as well as between code reading and code writing. A possible hierarchy for developing programming skills is suggested, with basic knowledge at the bottom, code tracing and code reading part of the intermediate level and code writing on the highest level.

3.4.4 Findings from Third Action Research Cycle

The third action research cycle continued to investigate statistical relationships between reading and writing code, as well as whether programming consists of a hierarchy of knowledge and skills (Whalley & Lister, 2009). This investigation focused on replicating and further investigating Lopez et al.'s (2008) study on the relationships between tracing iterative code, explaining code and writing code.

In Lister et al.'s (2009) replication of Lopez et al.'s (2008) study, they analysed data from an end-of-semester examination on an introductory course on Python. They used a non-parametric statistical analysis (the chi-square test), in contrast to the linear relationships that have previously been investigated. Consistent with the findings of Lopez et al. (2008), Lister et al. (2009) found that while skill in tracing is a requirement for code writing, a combination of tracing and explaining skills has a stronger influence on code writing ability. Their data too do not support the idea of a strict hierarchy. However, they argue that most students need a minimal competency in tracing to enable them to acquire the ability to explain code, and that these skills reinforce each other. Furthermore, a minimal competency in both tracing and explaining is required before being able to systematically write code. Once a student has acquired a minimal competency in all these skills, the skills will reinforce each other and develop in parallel (Lister et al., 2009).

The ITiCSE'09 BRACElet working group replicated the earlier analysis by Lister et al. (2009) on three new datasets, as well as Lopez et al.'s (2008) work on two new datasets (Lister et al., 2010). Both replications support the findings of the original study, namely that students who can explain code, in general, can trace code, and students who can write code can usually both trace and explain code. With regard to the ordering of tracing, writing and explaining, the working group concludes that there is some evidence that tracing is a lower-level skill than explaining or writing code, but that no results currently indicate a hierarchy between explaining and writing.

Venables et al. (2009) studied the performance reliability of end-of-first-semester novices on the questions in their own Java examination in order to determine whether they would find the same relationships as Lopez et al. (2008). They used non-parametric statistical tests to establish non-linear relationships. Venables et al. (2009) found that while there is a statistically significant relationship between the ability to explain code and to write code, the relationship is not linear. The same relationship was found between tracing and explaining. Furthermore, they also found that while a minimal competency at tracing is necessary for code writing, that minimal skill alone is not enough to allow code writing. However, there is a strong relationship between the combination of tracing and explaining with the skill of writing (Venables et al., 2009).

In addition, Simon and Snowdon (2011) investigated whether students who seem to be unable to explain the purpose of a simple code fragment, cannot do it because they are unable to determine the purpose of the code, or because they do not have the language ability to express the purpose. They used code-explaining questions, where students had to 'explain in plain English', and repeated the same questions in a multiple-choice question format with plausible options. They conclude that students, who fail code-explaining questions, are really unable to explain the purpose of the code, or to recognise it from a list of options (Simon & Snowdon, 2011).

In summary, these findings suggest the possibility that a novice programmer develops skills in a hierarchical order, as follows: At the bottom of the hierarchy are knowledge and understanding of basic programming constructs, such as basic definitions and data types, selections and iterations. The novice then learns to read code (that is trace, first non-iterative code and then iterative code). Once this skill becomes reliable, the ability to explain code develops. When students are reasonably capable of both reading and explaining, the skill to systematically write code develops. Tracing iterative code and explaining code therefore, form the intermediate levels of the hierarchy, with code-writing at the highest level. These skills do not necessarily develop in a strict order, but instead reinforce each other in a cyclical manner and develop in parallel. Furthermore, students should have a certain minimal ability to trace and explain code before they are able to show a minimal proficiency to systematically write code (Lister et al., 2010; Lister et al., 2009; Venables et al., 2009; Whalley & Lister, 2009).

3.4.5 Key contributions

The key contributions of the BRACElet project are based on the analysis of naturally occurring data in the form of students' examination responses in introductory programming courses (Lister et al., 2010). Clear et al. (2011) identified the central findings of the BRACElet project related to novices learning to program as follows:

- In contrast with academics who abstract to explain code on a relational level, novices are inclined not to do so, since they 'could not see the forest for the trees' (Lister et al., 2006).
- A student's degree of mastery of code tracing tasks is an indication of his/her ability to think relationally about code. Complete mastery of code tracing indicates an ability to think relationally (Philpott et al., 2007).
- Students' SOLO responses on code-reading ('explain in plain English') questions correlate positively with their performance on code-writing (Sheard et al., 2008).
- There is a correlation in performance between 'explain in plain English' tasks and code writing tasks, as well as between code tracing and code writing tasks. A possibility of a hierarchy of programming related tasks with knowledge of programming constructs at the bottom, 'explain in plain English', Parson's problems and tracing of iterative code on one or

more intermediate levels and code writing at the top, was identified (Lister et al., 2009; Lopez et al., 2008).

- A minimal level of tracing skill is required for code writing, but this in itself is not enough to enable code writing. Skill in code explanation combined with tracing skills, predicts performance in code writing (Venables et al., 2009).

In addition, the BRACElet project has contributed guidelines and toolkits for longitudinal multi-national projects (Whalley & Clear, 2007). Several guidelines for the analysis of assessments and students code have also been published, including the following:

- Guidelines for using Bloom's taxonomy as a guide in the design of programming assessments or programming problems (Thompson et al., 2008).
- Guidelines for using SOLO to reliably classify student responses to questions where they have to explain code (Clear, Whalley et al., 2008).
- Guidelines for applying SOLO to setting programming assessments and tasks (Thompson, 2010).
- Guidelines and a process for using SOLO to categorise student responses to code writing questions (Whalley et al., 2011).

BRACElet has therefore made a substantial contribution to the teaching of introductory programing that can be used as a basis for further research in this area.

3.5 Theoretical basis for BRACElet's work

During the third action research cycle, the BRACElet group began to investigate a theoretical foundation for their results. Initially, links with research in mathematics education were investigated (Lister et al., 2010). This was followed by a neo-Piagetian perspective on novice programmers' development (Lister, 2011).

3.5.1 Research in mathematics education

At the eleventh BRACElet workshop, participants began to link the SOLO taxonomy with research in mathematics education as a theoretical basis for BRACElet's work (Lister et al., 2010; Lister & Edwards, 2010).

Research in mathematics education divides knowledge into two types namely conceptual and procedural knowledge (McCormick, 1997). Sfard (1991) explains procedural knowledge as operational or process understanding that considers how something can be computed. In procedural knowledge a concept is seen as an algorithm for manipulating things (Sfard, 1991). This allows a student to apply the concept to some data. Conceptual knowledge is described as structural or object understanding, where a concept is described by its properties, and treated as an entity. This, in turn, allows a student to reason about a concept, by using the concept itself as data. BRACElet participants place operational understanding on the multi-structural level or lower in the SOLO taxonomy, and structural understanding on the relational level of the SOLO taxonomy (Lister & Edwards, 2010).

According to Sfard (1991), concept formation occurs in three phases from process to object understanding, namely –

- interiorisation, where the student becomes familiar with applying the process to data;
- condensation, when the student abstracts the process in more manageable parts, and ultimately abstracts it into input-output behaviour while still viewing it as an algorithmic process; and
- reification when the concept is seen as a unified entity, understood by its characteristics, and can be used as a primitive object in other concepts.

Since these phases build upon one another, a student who has reached object understanding about a concept still maintains the process understanding about that concept. Also, once a concept has been reified, it can be used as a building block or primitive component in the formation of a higher-level concept, in a hierarchical manner. When relating this to the SOLO taxonomy, a concept that is understood at the highest SOLO level (extended abstract), can be understood at the lowest SOLO level (unistructural) when it becomes a primitive component in a new concept (Lister et al., 2010).

BRACElet considers skills in computer programming as similar to procedures in mathematics education research, since both represent a set of step-by-step instructions. BRACElet explores skills acquisition in contrast to mathematics education research where concept acquisition is studied. This is part of the fundamental difference between mathematics that focuses on acquiring concepts and computer science, which has both practical and conceptual learning goals. BRACElet recognises strong links between theories of learning in mathematics and the SOLO classification used in their research, though the extent to which conceptual hierarchies apply to computer science is not clear (Lister et al., 2010).

An application of mathematics educational research to BRACElet's work was published by Philpott, Clear and Whalley (2009). They assessed the program comprehension skills of intermediate level students with a pathfinder algorithm simulation task. Students' comprehension levels were categorised by Philpott et al. (2009) according to the SOLO taxonomy and then linked to the process of concept formation as described by Sfard (1991). Philpott et al. (2009) argue that the SOLO phases of 'quantitative' and qualitative' as indicated in Table 3.2 map to Sfard's (1991) concept and object understanding, and may be used to measure the level of abstraction in computer science education. Philpott et al. (2009) also present a guided discovery learning model that links tasks to the three different stages of concept development proposed by Sfard (1991).

3.5.2 A neo-Piagetian perspective on novice programmers' development

Neo-Piagetian theory was the inspiration for the SOLO taxonomy (Lister, 2011). This prompted Lister (2011) to investigate a neo-Piagetian perspective to explain observations about novice programmers in BRACElet's research. Neo-Piagetian theory is derived from classical Piagetian theory (Piaget & Inhelder, 1969). Classical Piagetian theory focuses on a child's cognitive development in terms of abstract reasoning from infancy up to adulthood. Neo-Piagetian theory instead focuses on the cognitive development of people of any age while they acquire knowledge in a specific problem domain (Teague, Corney, Fidge, Roggenkamp, Ahadi & Lister, 2012).

Piaget (Piaget & Inhelder, 1969) identified the following four stages in the cognitive development of children up to adulthood: sensorimotor, pre-operational, concrete operational, and formal operational. During the first two stages, up to about age seven, motor activity, followed by language and early symbol manipulation respectively develop. In the third stage, the concrete operational stage, from about seven to 12 years, a grasp of conservation of matter, of causality and the ability for classification of concrete objects develop. In the fourth stage, the formal operational stage, from around 12 years to adulthood, individuals exhibit an ability to think abstractly, systematically, and hypothetically, and to use symbols related to abstract concepts. At this stage individuals are capable of thinking abstractly and scientifically. Piaget's theory links the cognitive development to biological maturity of the brain and assumes that children will display the same level of abstract reasoning in different areas (Piaget & Inhelder, 1969).

Neo-Piagetian theory (Morra, Gobbo, Marini & Sheese, 2007) argues that people, irrespective of their age, go through the same stages as they develop progressively more abstract reasoning when they gain experience in a specific problem domain. It is therefore possible for a person to demonstrate less abstract forms of reasoning in an area where the person is a novice, than in another area where the person is an expert. The increase in abstraction is considered to be the result of increasing the effective capacity of working memory through the development of 'chunking'. 'Chunking' happens when a set of associated data items is stored as a unit in long-term memory (Lister, 2011).

Each of the four stages in neo-Piagetian theory, as it applies to novice programmers' skills development, are discussed below.

3.5.2.1 The sensorimotor stage

In the first stage of cognitive development, the sensorimotor stage, novices do not have the abstractions to reason about a specific problem and cannot apply them (Teague, Corney, Fidge et al., 2012). Lister (2011) considers students with an ability of less than 50% to trace, to be at this stage. Since they can only trace code with great effort, they are inclined not to use it to develop programs

(Teague, Corney, Fidge et al., 2012). They also “do not experience an executing program as a deterministic machine” (Corney, Teague, Ahadi & Lister, 2012:2).

3.5.2.2 The preoperational stage

By the preoperational stage, the second stage in cognitive development, novices have acquired some appropriate abstractions, but their abstractions do not create a coherent comprehension of the problem domain, since they are still fragmented. A novice may therefore be able to apply a concept when prompted, but would not use it spontaneously or use it inappropriately (Lister, 2011; Teague, Corney, Fidge et al., 2012).

Novices at this stage can trace code, but usually do not abstract from the code to deduct a meaningful computation as executed by the code, since they see the lines of code as only weakly related (Lister, 2011). They use inductive reasoning to determine the function of a program segment, by manually tracing the code with a set of input values and then examining the output to determine the purpose thereof (Gluga, Kay, Lister & Teague, 2012).

Their inability to abstract makes it difficult for novices to use diagrammatic abstractions of code, and they cannot use ‘doodles’ to help them understand it. Their inability to ‘chunk’, overloads their working memory, so that they find it difficult to ‘explain in plain English’ (Lister, 2011).

3.5.2.3 The concrete operational stage

In the third stage, the concrete operational stage, novices can reason about abstractions of code, but it is restricted to familiar, real (‘concrete’) situations, not hypothetical situations (Lister, 2011; Teague, Corney, Fidge et al., 2012). A student at the concrete operational stage, can write small programs if presented with well-defined specifications, but struggles to write large programs from partial specifications (Teague, Corney, Fidge et al., 2012). These students tend to deal with abstraction by using specific examples to reduce the level of abstraction (Gluga et al., 2012).

This stage is characterised by the ability to reason about reversible processes, quantities that are conserved and transitive inference (Corney, Teague et al., 2012; Lister, 2011). Transitive inference refers to the ability to realise that if a certain relationship exists between two objects X and Y, and the same relationship exists between objects Y and Z, it will also exist between objects X and Z (Lister, 2011).

Students in the concrete-operational stage can relate code to diagrams, and see how lines of code work together to perform a computation (Corney, Teague et al., 2012). They should not need a concrete written trace to determine the purpose of a small section of code (Teague, Corney, Ahadi & Lister, 2013), but may derive its function just by reading it and using deductive reasoning (Gluga et al., 2012).

3.5.2.4 The formal operational stage

The formal operational stage is the last, most advanced and most abstract stage in cognitive development. This is the level at which expert programmers operate. At this stage people can reason logically, consistently and systematically. They also have a reflexive capacity, namely the ability to reflect about their own thinking (Lister, 2011; Teague, Corney, Fidge et al., 2012).

They can reason about hypothetical situations that they have never experienced, and be aware of what is known for certain, and what is known with some probability of being true. This allows them to use hypothetico-deductive reasoning to make a tentative inference from incomplete data and then systematically search for further data to confirm or deny the tentative inference (Lister, 2011). They can reason about unfamiliar situations, move from the abstract to the concrete, and apply problem-solving skills in unfamiliar situations (Corney, Teague et al., 2012). Students at this stage would have reached the learning objectives computing students should have acquired by the end of their first year, as identified by the McCracken group (McCracken et al., 2001) and mentioned in sections 2.4.2 and 3.2.

3.5.3 Applying the neo-Piagetian perspective

The neo-Piagetian perspective may be used to interpret some of the earlier results in BRACElet studies, as can be seen below.

BRACElet found that when students have to explain a code fragment, they frequently are able to explain what each line of code does (a multi-structural response in the SOLO taxonomy), but are unable to describe the purpose of the code which would be a relational level response. Those students who cannot express a relational response, are usually unable to write coherent programs (Lister & Edwards, 2010). This would indicate that such students are at the preoperational stage.

Philpott et al. (2009) found that a less than 50% ability to trace, indicates an inability to achieve relational thinking, which would allow a student to provide a summary of what code does in terms of the code's purpose, that is, to abstract. The Leeds working group (Lister et al., 2004) demonstrated that there are students who cannot trace code with 50% reliability at the end of the first semester of their introductory programming course. Lister (2011) considers these students to be at the sensorimotor stage in their cognitive development in the programming domain.

Students at the preoperational stage, who are unable to abstract to see the overall purpose of code, also find it difficult to use diagrammatic abstractions of code. This explains why Whalley et al. (2007) found that students at the multi-structural and unistructural level in the SOLO taxonomy do not use doodles to help obtain an answer. Thomas et al. (2004) found that beginner students were reluctant to use diagrams to trace code, while students with some high-school computing background, were more willing to do so. Presumably, the beginner students were still at the preoperational stage, while those with some computing background were at the next stage. The ‘middle novice programmers’ identified by Lister (2007), who could trace, but could not use diagrams in an end-of-semester examination, probably also were at the preoperational stage.

Whalley et al. (2007) found that students at the relational level in the SOLO taxonomy used doodles on the more difficult questions more than other students. Such students would be at the concrete operational stage and able to do so. Thomas et al. (2004) found that higher-achieving students do use diagrams, but that those who do not use diagrams, do even better than those who do. The better-achieving students, who do use diagrams, would be at the concrete operational stage, while better-achieving students who do not use diagrams would probably be at the formal operational stage (Thomas et al., 2004). The neo-Piagetian perspective is also supported by empirical evidence from studies aimed specifically at investigating this perspective (Corney, Teague et al., 2012; Teague, Corney, Ahadi & Lister, 2012; Teague, Corney, Fidge et al., 2012), as discussed below.

Corney, Teague et al. (2012) used questions provided by Lister to test his neo-Piagetian perspective in an end-of-semester exam to investigate novices’ ability to reason with quantities that are conserved; processes that are reversible; and properties that hold under transitive inference. These questions are intended to determine whether they have reached the concrete operational stage. They also explored the relationship between code explanation and concrete reasoning and came to the conclusion that some code explanation questions require a certain degree of concrete operational reasoning (Corney, Teague et al., 2012). They found evidence for students operating at the preoperational and concrete operational stage in reversing and conservation, but only weak support for transitive inference (Corney, Teague et al., 2012). The investigation confirms that some students are still at the preoperational stage of reasoning at the end of their first semester of introductory programming.

Teague, Corney, Fidge et al. (2012) describe how a series of small two-weekly tests and think-aloud sessions are used over a semester in an investigation into novices’ reasoning from a neo-Piagetian perspective. They found evidence that indicates that students operate at the first three neo-Piagetian levels, sensorimotor, preoperational and concrete operational. In another paper on the same study, Teague et al. (2013) interpret the think-aloud data within a neo-Piagetian framework, and demonstrate that some novices operate at the sensorimotor and preoperational stages, instead of the concrete operational stage targeted by instructors.

It seems as if the neo-Piagetian perspective provides a plausible explanation for the results of many of the studies in the BRACElet project. It may well be applicable to results of other studies on novice programmers, though this has not been investigated in the research covered by this study.

3.5.4 Implications of the neo-Piagetian perspective

Viewing novice programmers from a neo-Piagetian perspective holds some important implications for teaching and learning programming. Neo-Piagetian theory argues that progressing through the four stages while gaining experience in a new domain are natural behaviour (Corney, Teague et al., 2012; Lister, 2011). The empirical evidence from studies aimed specifically at investigating this perspective, clearly shows that there are students who are still at the lower levels at the end of their first introductory programming course. Most novices at the preoperational and concrete operational stages are unable to advance to the formal operational reasoning stage by themselves, and should be explicitly taught how to think relationally (Corney, Lister & Teague, 2011; Lister, 2011). However, instructors typically tend to teach at the formal operational level, or at least at the concrete operational level, and frequently use diagrams to explain. Students at the sensorimotor or preoperational stage would find this nearly impossible to follow (Teague, Corney, Fidge et al., 2012).

Students are also expected to write a considerable number of programs to learn to program, which students at the lowest two levels are unable to do (Corney, Teague et al., 2012; Lister, 2011). In order to assist students at the lower levels in reaching the concrete operational or formal operational level, different teaching methods that do not require students to write large amounts of code, need to be employed (Lister, 2011). In this regard Corney et al. (2011) suggest for example teaching roles of variables (Kuittinen & Sajaniemi, 2004; Sorva et al., 2007), namely typical usage patterns of variables, and using it in 'explain in plain English' questions.

Students at the sensorimotor and pre-operational stages should be identified and assisted in dealing with misconceptions and learning how to trace, as well as in developing abstractions (Teague et al., 2013; Teague, Corney, Fidge et al., 2012).

Constructivist theory claims that students actively construct new knowledge in a recursive process that combines the new knowledge with existing knowledge, that is, new knowledge is built on the foundation formed by prior knowledge (Ben-Ari, 2001). Consistent with constructivist theory, Teague et al. (2013:95) "believe that the ability to trace code is the foundation on which abstract reasoning about code is built. That is, while the ability to trace code requires little need to form abstractions, we believe that a novice will not begin to construct correct abstractions in their mind in the absence of the foundational skill of tracing code."

Teague et al. (2013) argue that novices' inability to trace code might explain the bimodal grade distribution that Dehnadi and Bornat (2006) and Robins (2010) found in introductory programming courses. Students who are unable to trace may lack the ability to create the abstraction required to write code, while those who have mastered the ability to trace, can make the abstractions necessary to write code. The former would constitute the lower hump of bimodal distribution, while the latter would fall into the higher hump (Teague et al., 2013). This would also tie in with the LEM effect proposed by Robins (2010) as discussed in Chapter 2 (see section 2.4.2.3), and BRACElet's proposed hierarchy, since students who cannot trace lack the prior skill required to learn to explain and write code.

Incorporating a neo-Piagetian perspective in planning and offering introductory programming courses will require developing new teaching methods and new learning experiences that include learning to trace and explain code, to assist students in progressing through the four stages. Students should also be assisted in learning to think relationally. This may result in retaining more students and a better pass rate rate.

3.6 Continuation of BRACElet's work

During the last two BRACElet workshops several directions for continuation of the past work were identified. Some of these are briefly discussed below.

3.6.1 Student annotations ('doodles')

The eleventh BRACElet workshop analysed student script notations ('doodles') from multiple institutions in an attempt to further Whalley, Prasad and Kumar's work (Lister et al., 2010). The eleventh BRACElet workshop followed the same approach as McCartney, Moström, Sanders and Seppälä (2004) who compared student annotations on skeleton questions (incomplete code fragments that have to be completed) and fixed-code questions (questions on the results of executing a code fragment). A large variation in the type of annotations used for synchronised tracing (tracing the values of a number of variables line-by-line through code) was noted, but no real trend could be determined. It was suggested that students who can explain code at relational level do not need to make annotations, as they may be more expert and can predict the output of a code segment without annotations (Lister et al., 2010). In a neo-Piagetian perspective such students would be at the concrete operational or formal operational stage.

3.6.2 Novices' understanding of the relationship between the concepts 'object' and 'class'

A follow-up study of an investigation into novices' understanding of the concepts 'class' and 'object' (Eckerdal, 2009; Eckerdal & Thuné, 2005), examined a possible hierarchy of how students learn aspects of concepts (Eckerdal et al., 2011). In particular, it focused on how novices understand the concepts 'class' and 'object' as a piece of program text (the aspect TEXT), the active behaviour of the program when it is executed (the aspect ACTION) and the modelling aspect (the aspect MODEL) of these concepts. The findings do not support a hierarchy but suggest that both TEXT and ACTION aspects may develop in parallel (Eckerdal et al., 2011).

3.6.3 Misconceptions about assignment

The studies that explored Lister's neo-Piagetian perspective used screening questions to exclude students at the sensorimotor stage (Corney, Teague et al., 2012; Teague, Corney, Ahadi & Lister, 2012; Teague, Corney, Fidge et al., 2012). The screening questions test whether students understand variables, assignment and ability to trace simple code. Following up on the results of the screening questions, Simon (2011) analysed students' responses on questions by testing their knowledge on assignment and sequence. As was mentioned in section 2.4.3.2, he found that it appeared as if many students in their first, second and even third programming courses do not understand the semantics of the assignment statement, or that a sequence of statements are executed sequentially, and possibly both (Simon, 2011). In a neo-Piagetian perspective, these students would still be at the sensorimotor stage.

3.6.4 Examination question classification

While the seventh BRACElet workshop had as an aim to develop an ideal examination paper (Clear, Edwards et al., 2008; Clear et al., 2009), the twelfth workshop identified a survey and an analysis of questions used in examination papers for novices (Clear et al., 2011; Lister & Edwards, 2010).

Whalley et al. (2011) developed a framework to classify student responses to code-writing examination questions. A classification scheme to investigate the characteristics of examinations questions themselves were also explored in a pilot project (Sheard et al., 2011; Simon et al., 2012).

3.6.5 A longitudinal study into the development of novices – examination question generation and benchmarking

The interest in a longitudinal study into the development of novices, resulted in a project to investigate novice programmers during the first three semesters of their programming studies (Corney, Lister et al., 2012). The aim was to use students' performance on in-class tests and certain examination questions to determine at what stage of their studies they are able to demonstrate understanding of various concepts. The project intended to create an archive of in-class and examination questions, as well as a repository of students' in-class test papers and examination scripts, together with their performance data for the tests and examinations with the purpose of benchmarking students on those questions (Corney, Lister et al., 2012).

Corney, Lister and Teague (2011) investigated the development of novice programmers during their first semester in a longitudinal study. They used code that swapped the values of two variables as the simplest case of a SOLO relational response in two tests during the semester. They then compared the results of students in those tests with their end-of-semester examination results in a similar swap question. Their findings indicate that students, who could successfully explain the swapping code in week 3 of the semester, were more likely to write correct swapping code in week 5 and also performed better code writing at the end of the semester (Corney et al., 2011). This indicates that the problems students experience in learning to program probably start very early in the semester. The researchers do not claim that code writing is dependent on the ability to explain code, but consider the ability to understand and reason about code as a possible third variable in the link between code writing and explaining (Corney et al., 2011). Replications of their study at other institutions produced similar results (Murphy, Fitzgerald et al., 2012; Murphy, McCauley & Fitzgerald, 2012; Teague, Corney, Ahadi & Lister, 2012).

Murphy, Fitzgerald et al. (2012) investigated the relationship between novices' ability to explain code segments and their ability to write code in a two-part final examination where students explained code in the written part and used computers to write code in the programming part. Their results showed that writing code and explaining code are highly correlated, confirming results from earlier studies (Lister et al., 2010; Lopez et al., 2008; Venables et al., 2009), and that "the reasoning abilities common to both writing and explaining code are non-trivial" (Murphy, Fitzgerald et al., 2012:117). Furthermore, Murphy, Fitzgerald et al.'s (2012) findings confirm that this relationship also holds for computer-based code-writing questions and not only for paper-based code-writing as in the previous studies. The data were collected over four semesters, where for the last two semesters, students were exposed to 'explain in plain English' questions during the semester. Despite this, no statistical difference could be found between code-explaining abilities of students from the first two semesters and those from the second two semesters. Murphy, Fitzgerald et al. (2012) speculate that should code-explaining be incorporated in teaching, a strategy needs to be developed to do so.

Studies aimed at investigating the neo-Piagetian perspective (Corney, Teague et al., 2012; Teague et al., 2012; Teague, Corney, Fidge et al., 2012), discussed in the previous section, were also part of this project.

3.6.6 BABELnot

The BABELnot[6] project resulted from BRACElet's work and its continuation in the form of the examination question classification project (section 3.6.4 above), the project to investigate novice programmers' development during the first three semesters (section 3.6.5 above) and Lister's work on neo-Piagetian theory (section 3.5.2) together with the course and unit of study portal (CUSP) at the University of Sydney. The CUSP project captures and maps curriculum goals to relevant degrees. Each graduate competency is in turn mapped to each assessment and learning outcome within each

[6] The name BABELnot is deliberately similar to that of the BRACElet project, which uses the capitalisation to reflect its continuation of the BRACE project. BABELnot evokes the biblical Tower of Babel which could not be completed because its builders lost the ability to communicate with each other. BABELnot intends to help overcome the challenge of communication between programming educators by developing a common understanding about standards and assessment. (Lister et al., 2012).

subject of a degree. BABELnot merges CUSP, the examination classification project and examination question generation and benchmarking project (Lister et al., 2012).

The BABELnot project aims to develop a framework for describing the learning goals and assessment for programming for the first three programming subjects. An archive of examination questions and performance data from real students for a subsection of the archived examination questions will also be collected (Lister et al., 2012).

3.7 Summary and conclusion

This chapter is a continuation of the literature review from Chapter 2, with the purpose of continuing to provide a context and theoretical basis for the research presented in this document. In particular, it focused on the BRACElet project's contribution to understanding the development of novice programmers and the role of tracing in that.

In Section 3.2 the studies that motivated the BRACElet project were introduced, and in section 3.3 a brief history of the thirteen workshops and three action research cycles that constituted the BRACElet project was presented.

Section 3.4 covered BRACElet's guiding principles for conducting such a multi-institutional, multi-national study, including their adaptations of Bloom's taxonomy for computer science and the SOLO taxonomy for classifying student responses on examination questions. This section also presented the findings in each of the three action research cycles during the project as well as BRACElet's key contributions. Of particular interest here, is the possible hierarchy in which students learn to program proposed by BRACElet, in which tracing and code explaining form part of the intermediate level with code-writing at the top of the hierarchy.

Two possibilities considered as a theoretical foundation for BRACElet's work, research in mathematics education and a neo-Piagetian perspective, were discussed in section 3.5. According to the neo-Piagetian perspective a novice programmer goes through four stages (sensorimotor, preoperational, concrete operational and formal operational) while developing the skill to program. Each of the four stages was described and some of the results of the BRACElet project were the interpreted with a neo-Piagetian perspective. The implications of applying a neo-Piagetian perspective to teaching and learning of programming were then considered. Viewing the four stages as natural steps in learning to program implies that it has to be taken into account when teaching programming. Introductory courses should be adapted accordingly. This will require developing new teaching methods, with more emphasis on teaching novices to trace and explain code, before they have to write large amounts of code, especially if tracing is seen as a foundational skill required to develop abstractions (Teague et al., 2013) and reasoning abilities common to both writing and explaining code are viewed as non-trivial (Murphy, Fitzgerald et al., 2012).

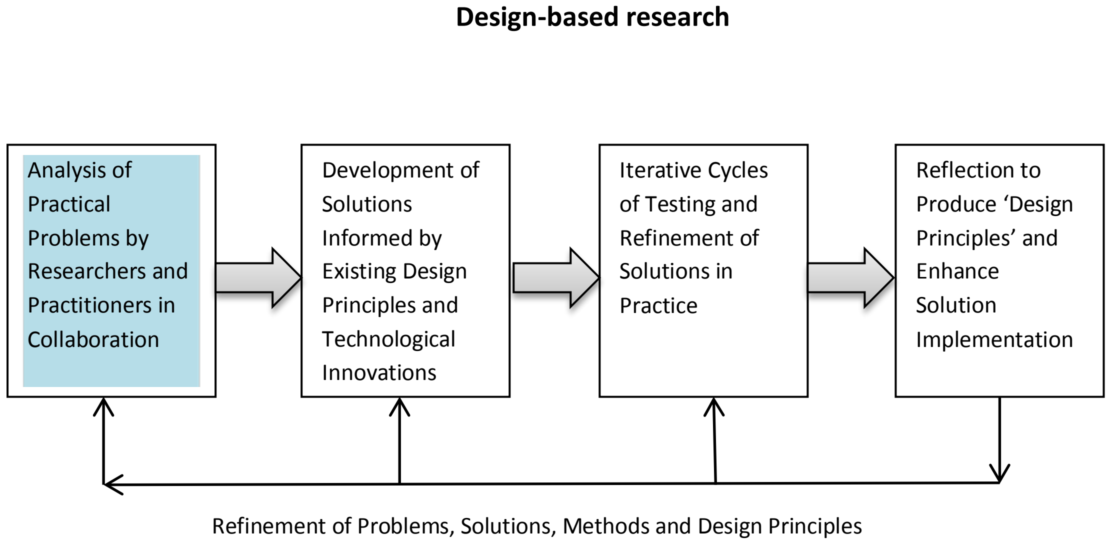
Section 3.6 presented a brief overview of some of the extensions of BRACElet's work, some of which confirms previous work, and others that confirm the neo-Piagetian perspective on novice programmers.

The BRACElet project contributed significantly to understanding and explaining the development process of novice programmers and the role of tracing therein. It also provides a rich foundation for further studies and extensions of its work.

This chapter and chapter 2 provided the context for the research. Chapter 2 provided the background to ODL, teaching programming in distance education, teaching introductory programming courses, tracing itself and visualization. This chapter, and in particular the neo-Piagetian perspective, contributed to understanding the development of novice programmers and the role of tracing therein. This was the premise for this research, namely that improving students' tracing skills would improve their programming skills and therefore their average marks, and the pass rate for the module COS1511.

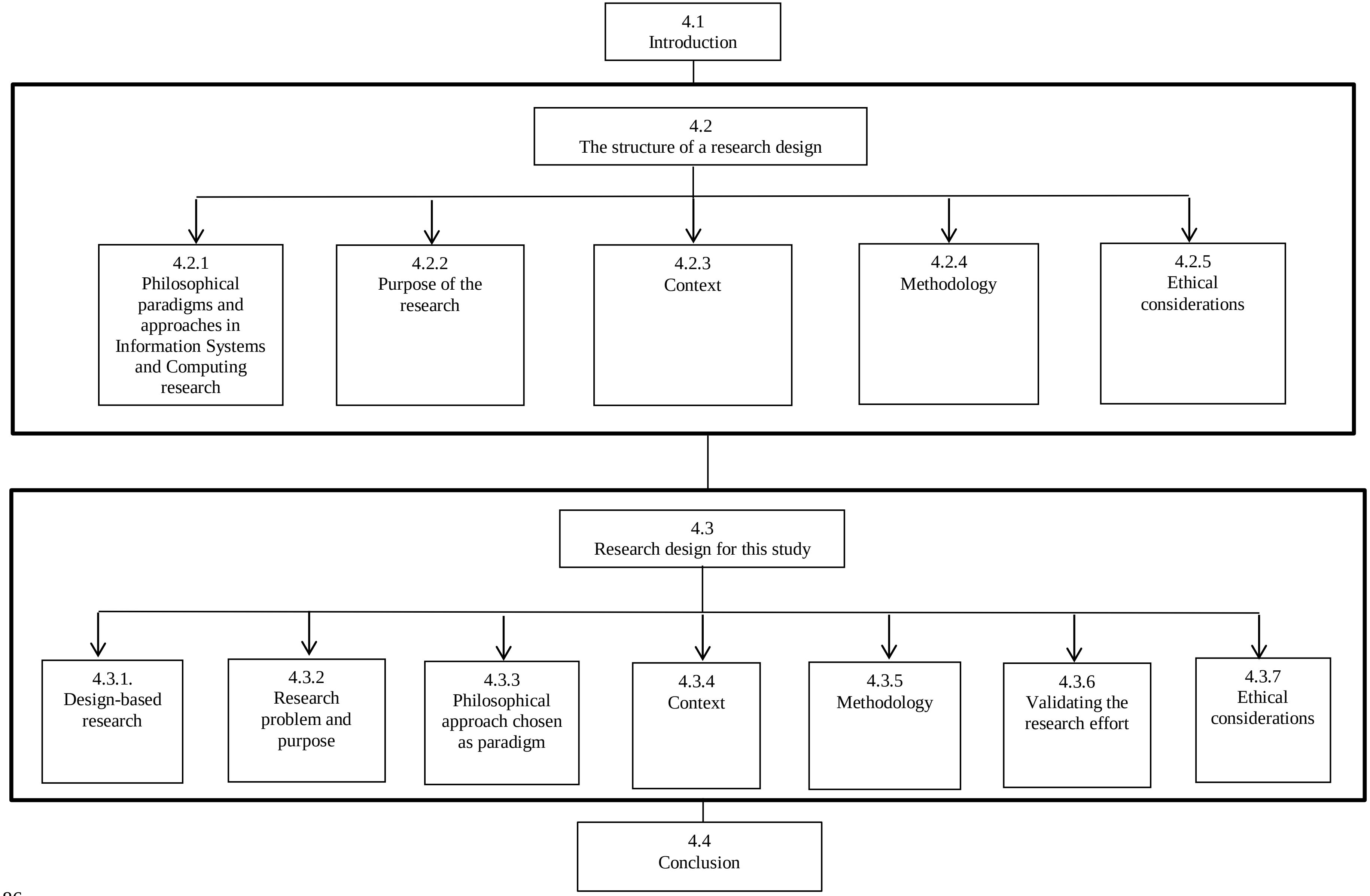
The next chapter addresses the research design and methodology followed to investigate the research questions.

Design-based research phase covered in Chapter 4


Design-based research
Analysis of Practical Problems by Researchers and Practitioners in Collaboration
Development of Solutions Informed by Existing Design Principles and Technological Innovations
Iterative Cycles of Testing and Refinement of Solutions in Practice
Reflection to Produce 'Design Principles' and Enhance Solution Implementation
Refinement of Problems, Solutions, Methods and Design Principles

Phase	**Element**	**Position**
Phase of design-based research (Reeves, 2006)	*Topics/elements that need to be addressed*	*Position in this thesis*
PHASE 1: Analysis of practical problems by researchers and practitioners in collaboration	Statement of problem	Chapter 1, Section 1.3.1 Chapter 4, Section 4.3.2.1
	Consultation with researchers and practitioners	Chapter 4, Section 4.3.2.1 and section 4.3.4.3
	Research questions	Chapter 1, Section 1.3.3 Chapter 4, Section 4.3.2.3
	Literature review	Chapters 2 and 3, Section 5.2
PHASE 2: Development of solutions informed by existing design principles and technological innovations	Theoretical framework	Chapter 5, Section 5.2
	Development of draft principles to guide the design of the intervention	Chapter 5, Section 5.3
	Description of proposed intervention	Chapter 5, Section 5.5
PHASE 3: Iterative cycles of testing and refinement of solutions in practice	Implementation of intervention (First iteration) Participants Data collection Data analysis	Chapter 6
	Implementation of intervention (Second and further iterations) Participants Data collection Data analysis	Chapter 7
PHASE 4: Reflection to produce 'design principles' and enhance solution implementation	Design principles	Chapters 5, 6 and 7
	Designed artefact(s)	Available on course website
	Professional development	Chapter 8

Map of Chapter 4 (Research design and methodology)


4.1 Introduction
4.2 The structure of a research design
4.2.1 Philosophical paradigms and approaches in Information Systems and Computing research
4.2.2 Purpose of the research
4.2.3 Context
4.2.4 Methodology
4.2.5 Ethical considerations
4.3 Research design for this study
4.3.1. Design-based research
4.3.2 Research problem and purpose
4.3.3 Philosophical approach chosen as paradigm
4.3.4 Context
4.3.5 Methodology
4.3.6 Validating the research effort
4.3.7 Ethical considerations
4.4 Conclusion

Chapter 4 Research design and methodology

4.1 Introduction

The previous two chapters provided the background for this study in the form of the literature review. This chapter presents the research design and methodology applied in the research for this study. Section 4.2 provides a general overview of the structure of a research design and the aspects that should be addressed in a research design.

Section 4.3 describes the research design and methodology according to the aspects identified in section 4.2. An overview of design-based research, the approach used to construct the research design, is presented in section 4.3.1. In section 4.3.2 the reader is reminded of the research problem and purpose of the research, while in section 4.3.3 the philosophical approach chosen as paradigm for this research, is justified. Section 4.3.4 is a description of the context in which the research is conducted and in section 4.3.5 the methodology applied in the research, is detailed, while section 4.3.6 consists of a discussion validating the research. In section 4.3.7 the ethical considerations involved are discussed and section 4.4 consists of the conclusion and summary of the chapter.

4.2 The structure of a research design

According to Mouton (2001:55) “a research design is a plan or blueprint of how you intend conducting the research”. Durrheim (2006) sees a research design as a strategic framework acting as a bridge between the research questions and the execution of the research. The research design should therefore specify a “series of actions which will ensure that valid conclusions can be drawn from the research” (Durrheim, 2006:36). This requires decisions about theoretical understandings and assumptions about research held by the researcher (the philosophical paradigm), the aims and objectives of the research, and the methods and techniques used to collect the data and analyse it (methodology). During this whole process ethical considerations should be taken into account (Cheek, 2008). The context in which the research takes place also has an influence on the research design (Durrheim, 2006).

The following sections elaborate on each of these aspects.

4.2.1 Philosophical paradigms and approaches in information systems and computing research

The concept of a paradigm has different interpretations (Freshwater & Cahill; Mertens, 2012; Morgan, 2007). The idea of using a paradigm to describe researchers’ belief about how they create knowledge originated with Khun (1962/1996). According to Morgan (2007), Khun used this concept in more than 30 different ways in his book *The Structure of Scientific Revolutions*. The four basic ways in which the concept of a paradigm is used, are paradigms as worldviews, as epistemological stances, as shared beliefs among members of a speciality area, and as model examples of research (Morgan, 2007). Morgan (2007:54) recommends that these four pproaches be considered as follows:

> "Ultimately, it helps to think of these four increasingly specific versions of paradigms as nested within each other. The model examples researchers use to demonstrate the key content of their field reflect a set of shared beliefs about both the research questions they should ask and the methods they should use to answer them. Shared beliefs about research topics and methods are, in turn, based on epistemological stances that summarize researchers' assumptions about what can be known and how to go about such knowing. And at the broadest level, assumptions about the nature of knowledge and reality are an important component of each researcher's worldview."

In this research report a paradigm is regarded as a shared set of assumptions that determines the perspective a research community holds on doing research. In line with Morgans's (2007) explanation, this includes the epistemological stance and worldview associated with a specific paradigm.

Different paradigms have different ontological, epistemological and methodological assumptions that guide the methods used, the interpretation and the assessment of research (Durrheim, 2006; Morgan, 2007; Oates, 2006). The axiological assumptions in a paradigm also influence the research perspective (Vaishnavi & Keuchler, 2004). Ontology refers to the nature of the reality being studied, and what can be known about it (Durrheim, 2006). Epistemology concerns the nature of knowledge and the relationship between the researcher and knowledge (Creswell, 2003; Durrheim, 2006; Oates, 2006; Vaishnavi & Keuchler, 2004). It is "a broad and high-level outline of the reasoning process by which a school of thought performs its empirical and logical work" (Lee, 2004:6), that is how the researcher reasons to acquire knowledge. Methodology refers to the practical processes and procedures used to study the reality as perceived by the researcher (Creswell, 2003; Durrheim, 2006). Axiology refers to the values an individual or group holds and the reasons why (Vaishnavi & Keuchler, 2004).

Most research in Information Systems and Computing, are based on one of three different philosophical paradigms, namely positivism, interpretivism or critical research (Oates, 2006). Positivism and interpretivism are the most dominant paradigms in Information Systems and Software Engineering (Mora, Gelman, Steenkamp & Raisinghani, 2012). Pragmatism is also frequently used as the philosophical foundation for design research (Cole, Purao, Rossi & Sein, 2005; De Villiers, 2005; Hevner & Chatterjee, 2010; Kuechler, Vaishnavi & William L. Kuechler, n.d.), an emerging trend in Information Systems and Information Technology (De Villiers & Harpur, 2013; Hevner & Chatterjee, 2010; Hevner, March, Park & Ram, 2004). It is noted that according to Biesta (2010:97), "pragmatism should not be understood as a philosophical position among others, but rather as a set of philosophical tools to address problems."

The following paragraphs provide a brief overview of positivism, interpretivism, critical research and pragmatism and a summary of the main beliefs in these four paradigms are presented in Table 4.1.

- Positivism holds that the world exists independently of humans and can be investigated objectively, through empirical testing of theories and hypotheses. Knowledge is discovered or generated through the scientific method, i.e. using experiments, observations and measurements to determine universal laws. Therefore, quantitative data analysis is mainly done by using mathematical modelling and proofs or statistical analysis. The researcher is objective, and personal values and beliefs do not influence the research, so that findings are consistent, value-free and replicable (De Villiers, 2012a; Oates, 2006).
- According to interpretivism, multiple subjective realities that are time and context dependent exist. Reality is constructed through social interaction and people's own perceptions. Interpretivist research attempts to understand phenomena by studying the meanings and values people ascribe to them. People are studied in their natural social environment through dialogue and interaction, and qualitative data and analysis are used to provide rich descriptions of findings. Both the researcher's and participants' values influence the findings, and findings may be subjective (De Villiers, 2012a; Oates, 2006; Wahyuni, 2012). Therefore researchers must be reflexive (Oates, 2006), and multiple data collections are frequently used to triangulate findings (De Villiers, 2012a).
- Critical research is focused on transformation in order to empower people. While critical researchers believe the world is created through social reality, like interpretivists, they also argue that social reality and history influence people's experiences and worldviews (Oates, 2006; Ponterotto, 2005). Research is reflexive (Oates, 2006) and influenced by the researcher's pro-active values (Ponterotto, 2005).
- Pragmatism accepts that there are "singular and multiple realities that are open to empirical inquiry and orients itself toward solving practical problems in the 'real world'" (Feilzer, 2010:8). Both the natural or physical world, and the social and psychological worlds are recognised, and people construct and base knowledge on the reality of the world they experience and live in (Creswell, 2014; Johnson & Onwuegbuzie, 2004). Pragmatists believe that research occurs in social, historical, political and other contexts (Creswell, 2014). Research philosophy is viewed as a continuum so that positivist and interpretivist perspectives are not exclusive (Feilzer, 2010; Wahyuni, 2012). The research question or problem is considered to be the most important aspect, with the focus on choosing the research approach that best addresses the problem, based on actions, situations and consequences

Table 4.1 Fundamental beliefs of research paradigms and approaches (Creswell, 2014; Lincoln, Lynham & Guba, 2011; Wahyuni, 2012).

	Research perspective			
Basic belief	**Positivist**	**Interpretivism**	**Critical research**	**Pragmatism**
Ontology: What is the nature of reality?	A single reality, knowable, probabilistic	Multiple realities, socially constructed	Multiple realities, socially constructed and influenced by prevailing systems	External, multiple realities, view chosen to best achieve an answer to a research question
Epistemology: What is the relationship between the researcher and that being researched?	Objective, dispassionate. Detached observer of truth	Subjective, that is values and knowledge emerge from researcher-participant interaction.	Transactional/Subjective, and value-mediated	Problem-centred, real-world practice oriented
Methodology: What is the process of research?	Observation: experimental/ manipulative, verification of hypotheses, quantitative, statistical	Participation, qualitative. Hermeneutical, dialectical.	Dialogic/dialectical	Pluralistic, focus on practical applied research, integrating both quantitative and qualitative methods to interpret the data
Axiology: What do researchers value as important products within inquiry research?	Truth: universal and beautiful, prediction	Understanding: situated and description	Aimed at social justice and transformation	Utility – focus on 'what works' and solutions to a problem

(Creswell, 2014; Johnson & Onwuegbuzie, 2004; Wahyuni, 2012). Accordingly, both qualitative and quantitative methods are used to derive knowledge (Creswell, 2014; Feilzer, 2010; Johnson & Onwuegbuzie, 2004; Wahyuni, 2012). Research should be 'useful' (Feilzer, 2010) – 'what works' – and provide solutions to problems (Creswell, 2014). Therefore pragmatism is value-oriented (Johnson & Onwuegbuzie, 2004).

The philosophical approach used in this research is justified in section 4.3.3.

4.2.2 Purpose of the research

The purpose statement of a study indicates why a specific study needs to be done and what the overall intent or objectives are. It is based on a need, namely the research problem, and then refined into research questions and objectives (Creswell, 2014; Oates, 2006).

The reader is reminded of the research problem that motivated this study in section 4.3.2. The purpose of the research is also described in section 4.3.2.

4.2.3 Context

The context refers to the situation or 'outside world' in which the research is done (Oates, 2006). The context is important, since the meaning of human creations, words, actions and experiences can only be determined in relation to both the personal and social contexts in which they occur. Data should be collected as far as possible in the natural context in which it occur, with minimal disturbance (Durrheim, 2006).

The context in which this research was done is addressed in section 4.3.4.

4.2.4 Methodology

The research methodology refers to the general approach the researcher uses to do the research. It guides the selection of methods and techniques that are used to sample, collect and analyse the data (Leedy & Ormrod, 2005; Tashakkori & Teddlie, 2010).

Three research approaches can be used, namely the qualitative, quantitative or mixed methods.

- Research with a **qualitative approach** aims to explore and understand the meaning individuals or groups ascribe to a social or human problem. This is typically done in a natural setting where data are collected through observation and in interviews. Documents and audio-visual material may also be used. The resulting text and visual data are then analysed and interpreted.
- Research with a **quantitative approach** tests objective theories by examining the relationship among variables. Scientific methods and procedures such as experiments and surveys are used

to measure these variables and the resulting numerical data are analysed with statistical procedures.

- In a **mixed methods approach** both qualitative and quantitative data are collected and the two forms of data are then integrated to provide a more complete understanding of the research problem (Creswell, 2014).

The methodology used in this research is described in section 4.3.5.

4.2.5 Ethical considerations

Ethical research is guided by the following four philosophical principles (Durrheim, 2006):

- *Autonomy and respect for the dignity of people* refers to the requirements for voluntary informed consent by research participants, as well as protection of individual and institutional confidentiality.
- *Nonmaleficence* demands that the researcher ensures that the research causes no harm or wrongs to the research participants.
- *Beneficence* requires the researcher to attempt to maximise the benefits of the research to research participants.
- *Justice* in research requires that researchers treat participants fairly and with equity during the whole research process.

In practice, these principles translate to certain rights that people directly involved with the research are entitled to, as well as responsibilities that an ethical researcher has to comply with.

The ethical considerations applied in this study are discussed in section 4.3.6.

4.3 Research design for this study

The previous section provided an overview of the components in a research design. In this section each of these components are described as they manifest in this research.

Both design-based research and action research have been considered as possible methodologies for this study. The iterative cycles of design, enactment, analysis and redesign (Design-based Research Collective, 2003) in design-based research, resembles action research, with the exception that the participants in action research assist in constructing the knowledge (Wang & Hannafin, 2005). In the ODL environment of Unisa, it would have been difficult to engage participants sufficiently to accomplish this. Therefore design-based research was chosen as research methodology for this study. Section 4.3.1 elaborates on design-based research.

In section 4.3.2 the research problem and the purpose of the study is reiterated, while justification for the philosophical approach chosen as research paradigm is offered in section 4.3.3. The context in which the research occurs is described in section 4.3.4, and in section 4.3.5 the methodology followed is described in detail. In section 4.3.6 validating the research effort is discussed. Ethical considerations are covered in section 4.3.7.

4.3.1 Design-based research

Design-based research, the educational variation of design research, is used to construct the research design for this study. Design research stems from design science as conceptualised by Herbert Simon in his classic book *The Sciences of the Artificial* (Simon, 1969/1981). Simon distinguishes between natural sciences in which natural objects and phenomena are studied; and design sciences or 'the sciences of the artificial', where man-made objects and artificial phenomena are studied. In Information Systems and Information Technology, design research is called *design science research*, while in educational technology and e-learning, it is termed *design-based research* (De Villiers, 2012b). It is noted that design-based research has been described with different terms in the literature, including *design experiments* (Brown, 1992; Cobb, Confrey, diSessa, Lehrer & Schauble, 2003), *design research* (Edelson, 2002; Oh & Reeves, 2010; Van den Akker, Gravemeijer, McKenney & Nieveen, 2006), *development research* (Van den Akker, 1999), *developmental research* (Conceição, Sherry & Gibson, 2004; Richey, Klein & Nelson, 2004) and *formative research* (Reigeluth & Frick, 1999). For the purpose of this research, *design-based research* is used.

Barab and Squire (2004) view design-based research as a series of approaches aiming to produce new theories, artifacts and practices to explain and influence learning and teaching in natural settings. Wang and Hannafin (2005:6) define design-based research as "a systematic but flexible methodology aimed to improve educational practices through iterative analysis, design, development, and implementation, based on collaboration among researchers and practitioners in real-world settings, and leading to contextually-sensitive design principles and theories". Design-based research delivers both a practical and a theoretical contribution by –

- using technology / an intervention to solve a complex practical real-world problem; and
- contributing to design theories and principles (Barab & Squire, 2004; De Villiers, 2012b; De Villiers & Harpur, 2013, Design-based Research Collective, 2003; Wang & Hannafin, 2005).

The features of design-based research have been extracted and synthesised from papers by Anderson and Shattuck (2012), Barab and Squire (2004), Cobb, Confrey, diSessa, Lehrer and Schauble (2003), De Villiers (2012b), De Villiers and Harpur (2013), the Design-Based Research Directive (2003) Mingfong, Yam San and Ek Ming (2010), Oh and Reeves (2010), and Wang and Hannafin (2005). According to these sources, design-based research is characterised by:

- Being situated in a real-world educational setting.

- Focusing on solving a complex problem by designing and testing an innovative intervention or artifact.
- Basing the intervention on learning/instructional theory.
- Dual outcomes in the form of both a practical intervention and a related theoretical contribution (design principles).
- Taking the context in which the research is done into account in both the design, evaluation and interpretation of the research.
- Collaboration between researchers, designers, practitioners and participants.
- Iterative cycles of "design, enactment, implementation, analysis and evaluation, and redesign" (Design-based Research Collective, 2003:5).
- Being reflective and flexible in revising and adapting the designed intervention.
- Being pragmatic – the design of the intervention should solve a real-world problem and lead to the development of practical design principles, patterns and/or grounded theories impacting on real educational settings – "the theory must do real work" (Cobb et al., 2003:10).
- Using mixed methods with a variety of research tools and techniques to suit the research problem.
- Synergy between design and research that inform each other and develop concurrently.
- Rigorous accounts of the research process and findings.
- Communicating contextually-sensitive shareable theories to other practitioners and educational designers.
- Extending existing methodologies such as action research and instructional systems design.

The design-based research community has not yet identified and accepted one comprehensive research methodology (Mingfong et al., 2010; Morgan, 2013; Oh & Reeves, 2010; Plomp & Nieveen, 2009), though some general approaches have been proffered. Two of these approaches, respectively by Reeves (2006) and Bannan-Ritland (2003), are described for the purpose of this research. Reeves's (2000; 2006) approach is described to illustrate the difference between design research methods and traditional predictive research methods, while Bannan-Ritland (2003) offers a general model for conducting design-based research that corresponds with the stages in design-based research identified by Reeves.

Reeves (2000) distinguishes between design-based research methods and traditional predictive research methods. A diagrammatic view of the stages in traditional predictive research in comparison with the iterative stages in design-based research, is shown in Figure 4.1 (Reeves, 2006:59). In traditional predictive research, theoretical findings are rarely applied in practice. This is due to a number of reasons, but mainly because the theory lacks applicability in the real-world contexts of practitioners. In contrast, one of the primary advantages of design-based research is that the collaboration between practitioners and researchers allows for contextual solutions and implementation thereof to real-world problems.

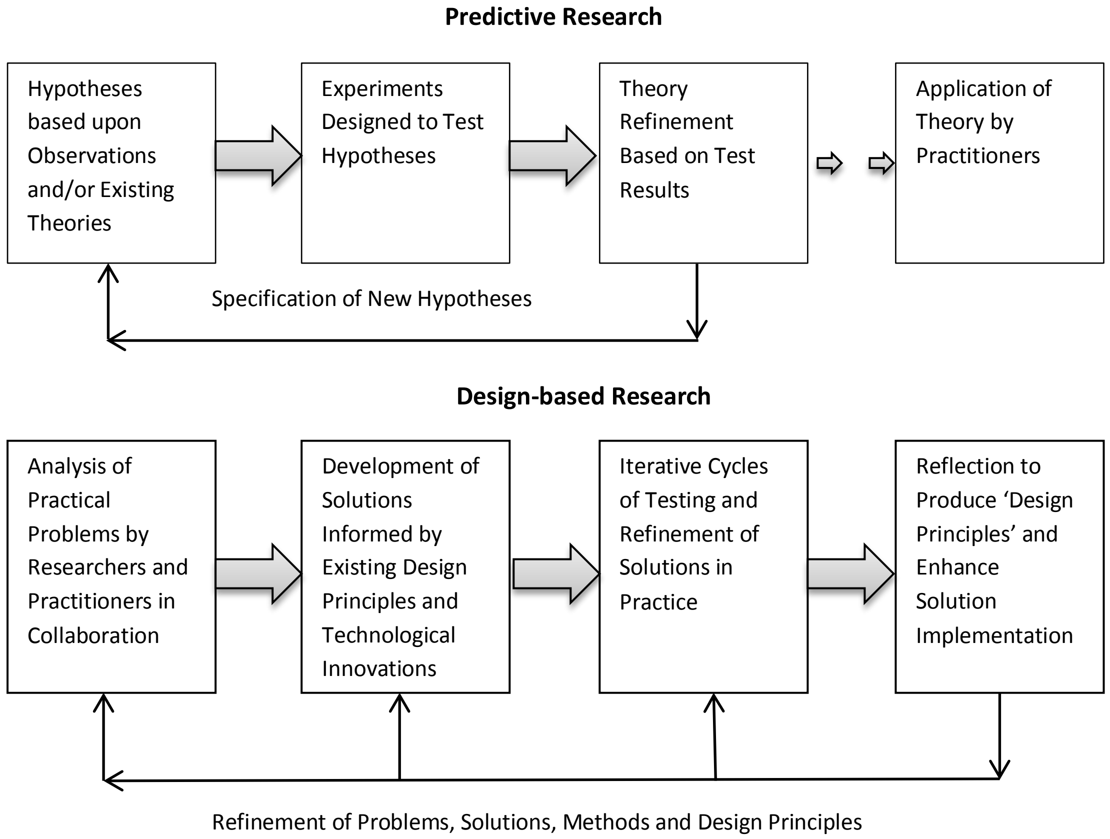

Predictive Research
Hypotheses based upon Observations and/or Existing Theories
Experiments Designed to Test Hypotheses
Theory Refinement Based on Test Results
Application of Theory by Practitioners
Specification of New Hypotheses
Design-based Research
Analysis of Practical Problems by Researchers and Practitioners in Collaboration
Development of Solutions Informed by Existing Design Principles and Technological Innovations
Iterative Cycles of Testing and Refinement of Solutions in Practice
Reflection to Produce 'Design Principles' and Enhance Solution Implementation
Refinement of Problems, Solutions, Methods and Design Principles

Figure 4.1 Predictive and design-based research approaches in educational technology research (Reeves, 2006:59)

Bannan-Ritland (2003) offers a general model for conducting design-based research with the Integrative Learning Design Framework (ILDF). The ILDF contains the following four phases (Bannan-Ritland, 2003; Oh & Reeves, 2010):

1. During the *Informed Exploration* phase the problem identification, literature survey, problem definition, needs analysis and the audience characterisation are done to determine preliminary design theories and principles.
2. During the *Enactment* phase the initial intervention is designed and refined into a more substantial prototype in series of small micro-cycles, influenced by evaluations during the local impact evaluation phase.
3. In the *Evaluation: Local Impact* phase the local impact of the intervention is evaluated. Data are iteratively collected and analysed to simultaneously do formative evaluation of the intervention and develop theory, developing into a more summative evaluation of the study's results and products. The data collected in formative evaluation serve to identify gaps, issues

and problems that have to be addressed to increase the effectiveness and utility of the designed intervention.

4. In the *Evaluation: Broader Impact* phase outcomes are disseminated in the form of publications as well as adoption and adaption of the designs and theories to a broader context. The consequences of using the products of the research are also considered.

Reeves' (2006) four stages of design-based research show correspondences with Bannan-Ritland's (2003) ILDF. Reeves' first stage, the analysis of practical problems in collaboration with practitioners, resembles the Informed Exploration phase in the ILDF, while his second stage, the development of solutions informed by existing design principles and technological innovations, is similar to the Enactment phase in the ILDF. Reeves' third stage, iterative cycles of testing and refinement of solutions in practice, is a combination of the Enactment and the local impact Evaluation Phase in the ILDF. Reeves' fourth stage, reflection to produce design principles and enhance solution implementation, is included in the broader impact Evaluation Phase in the ILDF.

Compared to other methodologies where certain dominant methods are used to collect and analyse data, in design-based research any appropriate approach may be followed, as justified by the design researcher's needs (Bannan-Ritland, 2003; Oh & Reeves, 2010). A combination of methods is used to collect data from multiple sources to increase objectivity, reliability, validity and applicability (McKenney, Nieveen & van den Akker, 2006; Wang & Hannafin, 2005). Furthermore, since design-based research is conducted in real-world settings, data are collected from actual learners (Oh & Reeves, 2010). Methods may differ and change according to new needs and issues that emerge during the research process. The research focus may also change (Wang & Hannafin, 2005).

Context plays an important role in design-based research. Design-based research is conducted in natural settings. Therefore the design of an intervention begins with an assessment of the local context and its limitations (Anderson & Shattuck, 2012; Mingfong et al., 2010). Design researchers design and study interventions and learning environments in collaboration with practitioners to gain insights into how best to adapt and employ the intervention in new settings. In this way they become a part of the research context (Oh & Reeves, 2010). Outcomes are seen as the result of interaction between the designed intervention, human psychology, personal histories or experience and the local context (Hoadley, 2004). "The intervention as enacted is a product of the context in which it is implemented" and therefore it is also (an) outcome of the research (Design-based Research Collective, 2003:5).

In the following two sub-sections the challenges and advantages of design-based research as well as ensuring validity in design-based research are discussed.

4.3.1.1 Challenges and advantages in design-based research

The real-world setting in which design-based research occurs, offers both challenges and advantages. The lack of control in the real-world situation in itself offers a challenge (Collins, Joseph & Bielaczyc, 2004; De Villiers, 2012b). It is demanding to "characterise the complexity, fragility, messiness and eventual solidity of the design and doing so in a way that will be valuable to others" (Barab & Squire, 2004:4). A team effort may be necessary which makes it more difficult to control the research process, but team members may provide additional insights and alternative interpretations (Cobb et al., 2003, Design-based Research Collective, 2003; McKenney et al., 2006). While it is difficult to generalise research findings from the local context, the knowledge generated is immediately applicable (Hoadley, 2004; Wang & Hannafin, 2005).

Due to the nature of design-based research, researchers play the dual roles of designer and researcher. Barab and Squire (2004:10) point out that "if a researcher is intimately involved in the conceptualisation, design, development, implementation, and researching of a pedagogical approach, then ensuring that researchers can make credible and trustworthy assertions is a challenge". When designers are involved in the evaluation, it may increase the chance for the evaluator effect (McKenney et al., 2006). The evaluator effect occurs when the presence of the evaluator distort findings because of participants' reactions to the evaluator; changes in the evaluator self; predispositions or biases of the evaluator; or evaluator incompetence (Patton, 1990). Designers may be less open to criticism (McKenney et al., 2006). Reactivity, the phenomenon that people change their behaviour because they know they are being tested or observed, may also occur (Leedy & Ormrod, 2005; Oates, 2006; Terre Blanche, Durrheim & Painter, 2006). Reactivity includes the Hawthorne effect and the experimenter effect (Oates, 2006; Terre Blanche et al., 2006). The Hawthorne effect (Adair, 1984) occurs when participants change their behaviour during evaluation because they know they are part of an experiment (Leedy & Ormrod, 2005; McKenney et al., 2006; Wang & Hannafin, 2005). The experimenter effect occurs when the researcher gives subtle unconscious clues about what he or she expects (Oates, 2006; Terre Blanche et al., 2006). This may lead to hypothesis guessing when participants attempt to react in a way that they think the researcher expects them to. Diffusion may also take place when knowledge of the treatment influences other participants (McKenney et al., 2006). However, this intense involvement provides inside information which allows for better insights into the strengths and weaknesses of the design (Anderson & Shattuck, 2012; McKenney et al., 2006).

Design-based research entails meticulously documenting the research context, design process and its implementation. The influence of changes in the intervention needs to be explored to determine how it affects local and general findings. There needs to be a trade-off between refining the intervention to maximise impact in the local context, while at the same time developing globally applicable knowledge (Design-based Research Collective, 2003). This requires significant effort and also generates large quantities of data that have to be collected and analysed, demanding considerable time and resources (Cobb et al., 2003; Oh & Reeves, 2010; Wang & Hannafin, 2005). Linked to changes in the intervention is the challenge to ensure rigour and validity while adapting research cycles to findings from previous cycles (Cobb et al., 2003, Design-based Research Collective, 2003; McKenney et al., 2006). The multiple iterations required in design-based research also make it difficult to set a time limit to a project (Anderson & Shattuck, 2012).

The challenges of design-based research makes it all the more important to ensure the validity of the research.

4.3.1.2 Ensuring validity in design-based research

According to Hoadley (2004:204) in design-based research "the validity of a study is the likelihood that our interpretation of the results accurately reflects the truth of the theory and the hypotheses under examination". This requires treatment validity, systemic validity and consequential validity. Treatment validity requires the treatment or intervention to represent the theory it tests. Systemic validity requires that the research and the implications drawn from it explain or answer the research questions, i.e. provide a fair test of the theories involved. Consequential validity refers to how the theories are applicable to decisions based on the research, that is, how interpreted results can be used in practice for future prediction and implementation (Hoadley, 2004).

In design-based research, the consequences of an intervention are used as evidence to support the validity of a claim (Barab & Squire, 2004). According to De Villiers and Harpur (2013:4) "The designed object is validated by its use." Therefore, processes of enactment in the cycle of design, enactment, analysis and redesign, should be meticulously documented to explain why outcomes occurred, since exact replication of a study is near impossible (Barab & Squire, 2004, Design-based Research Collective, 2003; Edelson, 2002). Documenting the design and research process continuously, thoroughly and systematically supports its validity, and allows for retrospective analysis, publication and dissemination in a broader context (Edelson, 2002; Gravemeijer & Cobb, 2006; Oh & Reeves, 2010; Wang & Hannafin, 2005). Dissemination and publication of the emerging design product and associated study, can also be used as tests of its efficacy (Kelly, 2006).

Triangulation from multiple data sources, iterative cycles of implementation and analysis, and using standardised measures or instruments are used to ensure the reliability of both findings and measures (Design-based Research Collective, 2003; Oh & Reeves, 2010; Wang & Hannafin, 2005). Researchers should use methodological practices consistent with other qualitative and quantitative research methods to confirm the trustworthiness and credibility of claims (Barab & Squire, 2004). Iterative cycles of study in a real-world scenario provide a better understanding of the intervention and in which context it has benefits, thereby producing more transferable and useful results (Amiel & Reeves, 2008).

Design-based researchers acknowledge the difficulty of ensuring experimental control and generalising research findings. They have to take into account "the intervention as enacted is a product of the context in which it is implemented" (Design-based Research Collective, 2003:5), and therefore may not have the expected result (Hoadley, 2004). Instead, the interventions could be regarded as small improvements in educational technologies and classroom or ODL practice that may have a long-term effect (Anderson & Shattuck, 2012).

The next section describes the real-world problem this research focuses on.

4.3.2 Research problem and purpose

Design-based research concentrates on solving a complex real-world educational problem by designing and testing an innovative intervention or artifact, while contributing to design principles and theories in this process. The real-world problem addressed in this study (discussed in more detail in section 1.3.1), with the corresponding aims and research questions, is reiterated below.

4.3.2.1 Research problem

The results of introductory programming courses at educational institutions typically have a bimodal distribution, with a low pass rate and a high drop-out, as well as a high number of distinctions (Bornat et al., 2008; Corney, 2009; Robins, 2010). Unisa is no exception in this regard. Table 1.1 in Chapter 1 shows the pass rates, number and percentage of distinctions and dropout rates for the introductory programming module at Unisa, COS1511 from 2011 to 2014. The demands and nature of the ODL environment at Unisa, as discussed in Chapter 2, may affect the situation.

Chapter 2 shows that many of the difficulties novices experience, can be related to lack of viable mental models for programming, and that they need to master certain threshold concepts that will allow easier learning of new concepts as proposed by the LEM effect hypotheses (Robins, 2010). The importance of teaching novices program tracing to address misconceptions and to assist them in developing mental models for programming, was also pointed out in Chapter 2. Furthermore, research by the BRACElet project, discussed in Chapter 3, has shown that novices first have to master tracing, that is, reading code, before they develop the ability to explain and write code.

Memory tracing and parameter transfer are taught in the introductory programming course at Unisa, COS1511, by means of static variable diagrams in the COS1511 Study Guide (Halland, 2011). The researcher noticed that students do not understand the static diagrams in the study guide, but that face to face explanation of the static variable diagrams in consultations, help them to understand it. When marking examination scripts for the follow-up first-year module, it is also clear from the kind of errors students make, that they lack knowledge and comprehension of the processes that occur in CPU memory during program execution. The knowledge gap is even more pronounced with regard to parameter transfer. This is supported by literature (Bruce-Lockhart & Norvell, 2007a; Milne & Rowe, 2002), and confirms the need for a better understanding of what happens in computer memory when a program executes.

This research is an attempt to address the lack of viable mental models in novice programmers and in doing so, to improve the pass rate of first-year programming students in COS1511 at Unisa. This was done by providing the COS1511 students with an interactive tutorial to teach them how to do memory tracing. The tutorial resembles a PV tool. It takes the form of a customized tutorial to teach students how to draw variable diagrams. The tutorial is based on the COS1511 Study Guide (Halland, 2011) since correspondence between the artifact and the related study material is a key factor in its acceptance as a learning tool (Naps, Röβling et al., 2003; Röβling, 2010). The tutorial was not intended as a tool to be used during program construction, but rather to teach students how to do manual tracing by themselves. This is in line with research that shows that students have to construct diagrams to trace code themself in order to make sense of the code (Thomas et al., 2004) and that engagement with visualization contributes to students' program comprehension (Ben-Ari et al., 2011).

However, the key features and the pedagogical benefits of visualizations are not clear (Urquiza-Fuentes & Velázquez-Iturbide, 2009b). Despite the general perception, research shows that visualization is not always pedagogically effective or used effectively (Shaffer, Cooper & Edwards 2007; Foutsitzis & Demetriadis 2008). A framework of guidelines from literature for using visualization to teach programming was compiled and used as a basis from which to develop the tutorial to teach students how to draw variable diagrams. This was then enhanced with lessons learnt during the development process and the evaluation of the tutorial itself and how students use it.

4.3.2.2 Aim

Design-based research delivers dual outcomes with a practical intervention as well as a related theoretical contribution in the form of design principles. Correspondingly, this research also had the following two aims:

- A practical intervention with the tutorial to teach students to draw variable diagrams. The purpose was to enhance comprehension in an open distance learning (ODL) environment in such a manner that it assists students in mastering the art of programming to the extent that it impacts the pass rate for the module.
- A theoretical contribution in the form of a framework of guidelines for designing, developing and using visualization tools to teach programming.

4.3.2.3 Thesis and research questions

In the light of the research problem and the aim of this research, the following thesis was formulated for this research, as indicated in section 1.3.3:

A framework of guidelines for using and creating visualization tools to teach programming, synthesized from literature and tested and refined through practical application, can be employed to develop a PV tool to teach introductory programming students in an ODL environment, to trace programs in order to improve students' programming skills.

To test this thesis the researcher investigated the following research questions:

1. What guidelines and principles for using and creating visualizations to teach programming, can be derived from literature?
2. Will a tutorial to teach tracing to visualize program execution and parameter transfer, based on the framework of guidelines, assist students in acquiring programming skills in an ODL environment so that it is noticeable in average marks?
3. How does students' biographical properties, their positive user experience, their use of tracing and the extent and manner of tutorial use, affect their ability to acquire programming skills in an ODL environment?
4. What lessons have been learnt through the practical testing and refinement of the visualization tool?

Data collected to answer research questions are interpreted according to a philosophical paradigm or approach. The philosophical approach used in this research is motivated below.

4.3.3 Philosophical approach chosen as paradigm

According to Hevner and Chatterjee (2010:9), "design science as conceptualised by Simon (1969/1981), supports a pragmatic research paradigm that calls for the creation of innovative artefacts to solve real-world problems". The prevailing world view of design research is therefore pragmatic (Cole et al., 2005; De Villiers, 2005; Hevner & Chatterjee, 2010; Kuechler et al., n.d.). Design-based research also has a pragmatic philosophical foundation (Barab & Squire, 2004; Wang & Hannafin, 2005). Accordingly, this research study follows a pragmatic approach.

Pragmatism is problem-centred and real-world practice oriented, similar to design-based research, with a focus on usefulness. In this study the focus was on finding a solution to the low pass rate for COS1511 that works. It was believed that finding a way to help students develop appropriate mental models of what happens in computer memory when a program executes, by teaching them to trace, would have a positive effect on students' performance. In the researcher's view, grounded on the characteristics of design-based research as described in section 4.3.1, this was the research approach best suited to this endeavour.

In agreement with pragmatism, the researcher acknowledged that each student has his/her own reality which differs according to personal background and experience so that multiple external realities exist. As a result, the tutorial might not have been useful to all COS1511 students. However, the tutorial would be deemed to be effective if it benefited the majority of students.

Pragmatists believe that research occurs in social, historical, political and other contexts (Creswell, 2014). As mentioned before, context also plays an important role in design-based research. In this research various contexts played a role. The next section elaborates on the contexts relevant to this study.

4.3.4 Context

Various contexts, in the form of the ‘outside world’ (Oates, 2006), had an influence on this study. This included the design setting, consisting of both the “classroom where design research is conducted and larger systems influences (for example the environment and culture of the school, student backgrounds)” (Wang & Hannafin, 2005:18). In this case, the ‘classroom’ was the ODL environment in which COS1511 is offered. The ‘larger system influences’ referred to the social and historical context which in turn shaped the students’ backgrounds, as well as their cultural background. The researcher’s context may also have had an effect on the study, since in this case the researcher was also a lecturer for COS1511. The researcher therefore played three roles, namely that of researcher, designer and practitioner. Each of these contexts is discussed below.

4.3.4.1 Local context

This research was conducted on students enrolled for COS1511, the first introductory course on programming, at Unisa, a large ODL university in South-Africa. Since Unisa is a comprehensive university, it offers both National Diplomas and degrees. COS1511 is offered to BSc students specialising in Computing or Informatics, or doing a general BSc; to students doing the National Diploma in Information Technology (NDINL/NDIT) and the National Diploma in Electrical Engineering (NDEEN); as well as to BA Multimedia, BA Communication Science and BEd students. It is also offered to students doing it for non-degree purposes and students following the access programme[7].

[7] Unisa is an ODL university. It has a policy of open access to allow students who wish to study at Unisa to enrol through alternative admission routes, provided they comply with certain minimum statutory requirements. Students can be granted conditional exemption on grounds of mature age (older than 23 years, with standard 10/grade 12 and satisfying certain conditions, or older than 45 without any school qualifications). The access programme also allows students who do not have matriculation exemption to enrol provisionally at Unisa. Once

When this research started in 2011, COS1511 was part of the programme mix for both the National Diploma: Information Technology (NDINL) and the BSc with Computer Science as major. Subsequently, as from 2013, a new curriculum for NDINL has been implemented and the NDINL was renamed the National Diploma in Information Technology (NDIT). In the new curriculum COS1511 has been replaced with another module. However, NDINL students who have to repeat COS1511 or who had been registered for the NDINL before 2013 were still allowed to register for COS1511.

Since COS1511 is offered to both degree and diploma students, the pre-requisites are not the same for all COS1511 students. In particular, NDIT, BA, BEd, non-degree purposes and access students do not require Mathematics to enrol, while all the other students should have a rating of at least 4 (50% – 59%) for Mathematics. Students also have varying levels of computer literacy, since computer literacy is not a prerequisite for all of these qualifications. Table 4.2 shows the prerequisites for the degrees and diplomas that COS1511 is offered to. No aptitude test has to be passed before enrolling for any degree or diploma (*Unisa Calendar Part 7*, 2010:6 & 43).

Table 4.2 Prerequisites for degrees and diplomas that COS1511 is offered to

Degree	**Prerequisites to enrol in COS1511**
BSc degree:	Matric exemption with Mathematics and English with a rating of 4, or equivalent (50% – 59%). All students who take Computer Science or Informations Systems as a major should meet the computer literacy requirement. This means students should have passed Computer Application Technology or Information Technology with a rating of 4 (new National Senior Certificate (NSC)) or passed Computer Studies (NSC) or hold an Industry Standard qualification in Computer Literacy issued within the previous five years. If not, then EUP1501 (End-User Computing) is a co-requisite for registration for COS1511 for these students.
BA and **BEd**	Senior Certificate with Matriculation Exemption or NSC with Degree admission or qualify for Conditional Exemption from the Matriculation Board
NDINL/NDIT	NSC diploma or Senior certificate
NDEEN	NSC diploma with Mathematics, English and Physical Sciences with a rating of 4

COS1511 is a semester module, offered twice a year via open distance education, with student numbers varying from approximately 1 600 to 3 000 students per semester. All the study material are made available on Unisa's course website for COS1511 and consists of –

- a printed Study Guide (Halland, 2011), also available in electronic format;
- a CD containing the prescribed compiler and IDE;
- the tutorial developed for this study; and

they have passed a number of modules applicable to the degree they wish to register for, they are allowed to register formally for that degree.(Unisa Online FAQ)

- tutorial letters providing general information about the module, assignments, solutions to assignments and previous examination papers (see for example https://my.unisa.ac.za/portal/site/COS1511-12-S1[8]).

In 2012, during the first cycle of testing the developed solution in practice, COS1511 was offered with 4 lecturers, 14 face to face tutors, 1 e-tutor and 6 external markers. Attending tutor classes were optional and an optional online forum for interaction with other students and the lecturers was provided. In 2012 two video conferences were offered during each semester.

In 2013, during the second cycle of testing the developed solution in practice, in the first semester, COS1511 was offered with 4 lecturers, 4 face to face tutors, 4 e-tutors plus an additional e-tutor for Science Foundation students[9] and 6 external markers. In the second semester of 2013 COS1511 was offered with 3 lecturers, 5 face to face tutors, 4 e-tutors plus 4 additional e-tutors for Science Foundation students and 6 external markers. Al students enrolled for COS1511 were allocated to e-tutors. Each e-tutor tutored approximately 200 students online. No video conferences were offered in 2013. Ten to 30% of the Science Foundation students interacted with e-tutors.

The difference in pre-requisites for the degrees and diplomas for which COS1511 is offered, the varying levels of computer literacy, the large student numbers and time constraints of the semester system as well as the ‘distance’ from lecturers and fellow students in ODL as discussed in section 2.2 in Chapter 2, are some of the challenges experienced in the ODL ‘classroom’ at Unisa.

4.3.4.2 Broader context

The broader context and theoretical basis for this study have been provided in Chapters 2 and 3. In Chapter 2 ODL, e-learning and MOOCs; teaching programming in distance education; teaching introductory programming courses; tracing and visualization are covered, while the focus of Chapter 3 is on the BRACElet project and their contribution to understanding how novices learn to program.

In section 2.2 of Chapter 2 the ODL environment at Unisa is discussed in particular. Factors in the broader ODL environment that affect students are briefly recapped. The language of tuition at Unisa is English. With a substantial number of African students (69% in 2012) as well as approximately 5% foreign students, many of the students have to study in their second or third language. This may place them at a disadvantage (Carter, Jernejcic & Lim, 2007; Gous & Roberts, 2014; Pillay & Jugoo, 2005). A large number of students are younger than 25 years, underprepared for tertiary education and struggle to adapt to it. Many students also come from a rural background, where infrastructure limits exposure to and availability of modern technology. The high cost of bandwidth in South-Africa,

[8] Access to the course website can be arranged on request.

[9] The Science Foundation identifies students who may struggle to master the course work and provide additional tutoring free of charge to them.

inadequate Internet access, as well as the low technical proficiency level of first-year students as indicated by Ragan in Ury (2005), also affect the level of support that can be given to these students. In addition, it makes some of the approaches mentioned in section 2.3 in Chapter 2, where teaching programming in distance education is addressed, difficult to implement successfully in the Unisa environment.

As a result, multiple social realities exist. Depending on their background, each student has a different social reality; for example a student that attended a previously disadvantaged school in a rural environment has a different social reality than a student that attended a former Model C school and took Computer Application Technology or Information Technology as a subject at school. Students with English as first language have different social reality from those with English as a second or third language. Students from overseas also have different social realities from SA students. Due to the different social realities and cultural milieus of students, the tutorial used as intervention in this PhD study, might have been effective for some students, while others might not have needed it.

As mentioned in Chapter 2, many of the problems the novices concerned experience, are due to their inadequate mental models for programming. This also applies to COS1511 students, who may, in the ODL environment where students have to study independently, struggle even more. In the light of the role of tracing in learning to program, teaching novice programmers in the ODL environment to trace in order to debug and to understand what a program does, may be all the more important.

The aspects identified in the broader context might all have impacted on this research.

4.3.4.3 Researcher's context

Design-based research is characterized by close collaboration between the researcher, designer, practitioners and participants. In this situation the researcher was also the designer, and a practitioner, since she was a lecturer for COS1511 during the study. These three roles require particular vigilance to ensure credible and trustworthy assertions (Barab & Squire, 2004). In particular, the researcher had to be aware of the possibility of the evaluator effect, the Hawthorne effect, the experimenter effect and hypothesis guessing as discussed in section 4.3.1.1 in this chapter.

However, acting as researcher, designer and practitioner, also provided an opportunity for the candidate to gain better insight into the strengths and weaknesses of the design because of the access to inside information. Reeves (2006) views the close collaboration between practitioners and researchers in identifying real problems; creating solutions based on existing design principles; and testing and refining the design principles as one of the primary advantages of design-based research. Being researcher and designer as well as practitioner gave the researcher in this study a distinct advantage to deal with the matter at hand.

4.3.5 Methodology

The methodology followed in this study is based on Reeves' (2006) four phases of design-based research as discussed in section 4.3.1 of this chapter. For each of these four phases, Herrington, McKenney, Reeves and Oliver (2007) identify certain elements that need to be described in a research proposal. These elements also had to be addressed in the implementation of the research. Table 4.3 is adapted from Herrington et al. (2007:4091) and shows where in this thesis each of the elements is implemented as well as the methods used to do so.

4.3.5.1 Phase 1: Analysis of practical problems by researchers and practitioners in collaboration

As can be seen from Table 4.3, the first phase had already been addressed in Chapters 1, 2, 3 and some of the preceding sections of this chapter. The remaining phases are addressed in the rest of the research report. The methods and techniques followed in phases 2 to 4 are discussed below.

4.3.5.2 Phase 2: Development of solutions informed by existing design principles and technological innovation

Phase 2 is addressed in Chapter 5. The theoretical framework was provided by a literature study to find guidelines for successful visualization. The literature study covered three fields, namely CER, educational psychology and computer graphics. Principles to guide the design of the intervention, the tutorial to teach students how to draw variable diagrams, were extracted from the guidelines for using visualization in teaching provided by these three fields.

A detailed description of the tutorial and design decisions for its development is provided in Chapter 5. While the researcher designed the tutorial, it was implemented by external developers. Initial testing was done by the researcher to determine whether the tutorial executes correctly. After testing, the developers adapted the tutorial as specified by the researcher. Once this had been completed the tutorial was deployed to the students.

Lessons learnt and guidelines discovered during the development process and the testing and refinement of the tutorial, provided further guidelines for developing and using visualization in teaching programming.

4.3.5.3 Phase 3: Iterative cycles of testing and refinement of solutions in practice

Two cycles were used to test and refine the tutorial to teach students to draw variable diagrams. The first cycle is described in Chapter 6, and the second cycle in Chapter 7. Mixed methods were used in the data collection and analysis in these cycles. The qualitative method was used to explain, elaborate, illustrate and clarify findings generated by the quantitative results (Greene, Caracelli & Graham, 1989). This provided contextual understanding for the quantitative findings, and assisted with a more comprehensive account of the inquiry. It also triangulated findings and thereby provided greater validity (Bryman, 2006).

Table 4.3 Phases of design-based research mapped against elements that need to be addressed in the research with the corresponding positions and methods in the thesis (adapted from Herrington et al., 2007:3)

Phase	**Element**	**Position**	**Method**
Phase of design-based research (Reeves, 2006)	*Topics/elements that need to be addressed*	*Position in this thesis*	*Method used to implement element*
PHASE 1: Analysis of practical problems by researchers and practitioners in collaboration	Statement of problem	Chapter 1, Section 1.3.1 Chapter 4, Section 4.3.2.1	Development of proposal
	Consultation with researchers and practitioners	Chapter 4, Section 4.3.2.1 and section 4.3.4.3	
	Research questions	Chapter 1, Section 1.3.3 Chapter 4, Section 4.3.2.3	
	Literature review	Chapters 2 and 3, Section 5.2	Literature review
PHASE 2: Development of solutions informed by existing design principles and technological innovations	Theoretical framework	Chapter 5, Section 5.2	Literature review to provide theoretical framework
	Development of draft principles to guide the design of the intervention	Chapter 5, Section 5.3	Synthesizing framework of guidelines from theoretical framework
	Description of proposed intervention	Chapter 5, Section 5.4	Design and develop PV tutorial
PHASE 3: Iterative cycles of testing and refinement of solutions in practice	Implementation of intervention (First iteration) Participants Data collection Data analysis	Chapter 6	First implementation of PV tutorial with evaluation using statistical analysis and usability study in HCI laboratory
	Implementation of intervention (Second and further iterations) Participants Data collection Data analysis	Chapter 7	Second implementation of PV tutorial with evaluation using statistical analysis and usability study in HCI laboratory
PHASE 4: Reflection to produce 'design principles' and enhance solution implementation	Design principles	Chapters 5, 6 and 7	Reflection on literature to extract design principles and on analysis of implementation to enhance PV tutorial
	Designed artifact(s)	Available on course website[10]	
	Professional development	Chapter 8	Reflection on professional development

[10] The tutorial is available on the following link: http://osprey.unisa.ac.za/download/Disk/tuts/COS1512/Variable%20diagram%20application%20%28for%20downloading%29/.

An important ethical consideration in this research was that the study should not impact negatively on any student by preventing access to the tutorial, similar to the principles followed by the BRACElet project as discussed in section 3.4.1. Therefore, it was not possible to use a control group as such, and factor analysis was done instead to determine the effect of a number of factors, one of which was students' use of the tutorial, on their final marks.

The two cycles used to test and refine the tutorial are presented as follows in this research report:

- **First cycle:** The tutorial was first deployed in 2012 by incorporating it in the study material for COS1511, for both the first and second semester of 2012. This constituted the first iteration of testing and refinement. Chapter 6 reports in detail on this cycle.
- **Second cycle:** The second iteration of the implementation occurred in 2013 and is discussed in Chapter 7. It followed a similar structure to the first cycle, after refinement of both the tutorial and data collection instruments based on the findings of the first cycle.

The characteristics of the participants, data collection and data analysis were similar in both cycles, and are briefly discussed below.

Participants

All students enrolled for COS1511 in 2012 and 2013 were participants of the research. Students registered for 2012 acted as participants in the first cycle and students enrolled in 2013 were participants in the second cycle. In the first semester of 2012, 2 877 students registered for COS1511 and in the second semester of 2012, 1 921 students. In the first semester of 2013, 1 623 students enrolled for COS1511 and in the second semester of 2013, 1 593 students[11]. During each of the two cycles, a number of these students were observed and eye tracked in the HCI usability laboratory at Unisa while using the tutorial to evaluate the user interface and find usability problems in the design (Nielsen, 1994). This was done to increase the effectiveness and utility of the designed intervention. Self-selection sampling was used, since participants had to come to the usability laboratory at the Muckleneuk campus of Unisa for the observation and eye tracking. Self-selection sampling occurs when researchers advertise their need for respondents on a particular topic and collect data from anyone who responds (Oates, 2006). It should be noted that these participants might not have been representative of the wider COS1511 population, since they might have thought it would be to their benefit to participate in the observation and eye tracking /usability testing of the tutorial (Oates, 2006).

[11] These numbers differ from those in Table 1.1 in Chapter 1, since Table 1.1 reflects only students still registered for the module at the time of exam sitting, and does not include students who cancelled the module. It was not possible to determine whether students cancelled the module before or after they had completed the questionnaire or were tested in the Human Computer Interaction laboratory.

Data collection

The data collection of the research consisted of the following:

- An optional multiple choice questionnaire (see Appendices B.1.1 and B.1.2) on the tutorial, to be completed with or after the first multiple choice assignment for COS1511 during the first cycle. A number of questions that require the use of variable diagrams were asked in this assignment, which should have encouraged students to use the tutorial to learn how to trace. The questionnaire contained questions on biographical data and previous experience, how students used the tutorial and their experience of using the tutorial. For the first semester in the second cycle two questionnaires were administered, one similar to the questionnaire used in the first cycle (Appendix B.2.1.1), to be completed with or after the first multiple choice assignment for COS1511, and another to be completed at the end of the semester (Appendix B.2.1.2). In the second semester of the second cycle only the second questionnaire from the first semester in the second cycle were administered (Appendix B.2.2.). In the questionnaires administered at the end of the semesters the questions from the first cycle were adapted or expanded to shed more light on the findings of the first cycle.
- The examination marks for each student.
- Direct live observation with eye tracking of a small number of COS1511 students in the HCI laboratory while using the tutorial. One participant at a time was observed. During observation, participants interacted with the tutorial and conducted specified learning tasks, including a retrospective comprehension test (see Appendix C.3 for a list of the learning tasks). Participants were observed in real-time to note their actions, menu selections, reactions and body language. Video recordings of the interaction were made for subsequent re-observation and in-depth analysis. Time taken on tasks, reflection, exercises, errors, and so on, was electronically recorded. The observations and eye-tracking (in particular, gaze replays) were used to determine how students use the tutorial.
- A questionnaire with open-ended, semi-structured questions (Appendix C.4) that students completed after the eye tracking and observation. The same questionnaire was used in both the first and the second cycle.

The multiple choice survey on the tutorial as well as assignment and examination marks were collected for both semesters in 2012 and 2013, while observation and eye tracking of students in the usability laboratory were done once in 2012 and once in 2013.

In this study, questionnaires (Appendix B) were used to collect data about the students' use and user experience of the tutorial, since there were a large number of wide-spread participants; and standardised data were required for the statistical analysis. The questionnaires were self-administered, with closed questions and pre-defined answers to make it easy to complete and analyse. The researcher used both her study leader and a professional statistician as sounding boards to assist with ensuring the content and construct validity as well as the reliability of the questionnaire. Content validity refers to making sure that the questionnaire generate data about the concepts being investigated, while construct validity is concerned with whether the questions measure what they are expected to measure. Reliability is concerned with whether the questionnaire would generate the same results if repeatedly administered to the same students (Oates, 2006). Construct validity are determined by Exploratory Factor analysis on the constructs in a questionnaire tested by a Likert scale (Terre Blanche et al., 2006). In the first implementation cycle there was only one construct, namely perception of positive experience, termed 'positive user experience'. Therefore construct validity could not be tested. In the second implementation cycle another construct was added to the questionnaires, namely perception of learning from the tutorial, termed 'learning experience'. However, since there were not enough responses to allow for exploratory analysis, construct validity could not be tested. Reliability of both of these constructs, that is, the internal consistency (Terre Blanche et al., 2006), was however tested by item analysis. The disadvantages of using questionnaires in this scenario included not being able to correct misunderstandings, offer explanations or help, query disparities between answers or check the truthfulness of answers. The pre-defined answers might have frustrated participants so that they refused to partake, and could also have biased respondents to the researcher's viewpoint (Oates, 2006).

While the questionnaires gave an indication of user experience, eye tracking in a usability laboratory was used to observe how students used the tutorial, and so investigate usability. Eye tracking consists of recording and measuring eye movements with a screen equipped with a built-in eye tracking device. Most eye tracking studies analyse patterns of visual attention of individuals when performing tasks such as reading, scanning or searching. Eye-tracking equipment allows for recording and replaying the records of eye movement, while software identify and analyse patterns of visual attention when performing a task (Djamasbi, 2014).

People only see when they focus overt attention on an object. A pause of eye movement on a specific area is called a fixation. The rapid movements between fixations are called saccades. Since information can only be perceived and interpreted information when the eyes fixate on it, there will be more or longer fixations on more complicated, confusing or interesting features. The data created by eye tracking consists of gaze plots and heatmap visualizations. A gaze plot shows the movement sequence and position of fixations and saccades on an observed image. The size of a dot gives an indication of the duration of a fixation, while the dots are numbered in the order in which fixations occur. A heatmap highlights the areas of the image where participants fixated. Warm colours such as red or orange will indicate longer fixations or many fixations on the same area (Djamasbi, 2014). Since eye-tracking data only provides an indication of how long and where a participant fixated, it does not give an indication of the success or comprehension of the participant. Additional performance measures such as retrospective comprehension tests or think-aloud feedback from the participant is required to correctly interpret the data (Hyönä, 2010). In addition, the following had to be kept in mind to enhance validity in eye tracking (Poole & Ball, n.d.):

- Eye trackers can have difficulty tracking participants with glasses or contact lenses since that interrupts the normal path of reflection. Large pupils and lazy eyes may also be problematic.
- Participants in eye-tracking should perform well-defined tasks to attribute eye movements to actual cognitive processing.
- Visual distractions should be eliminated.
- Filtering and analysis should be performed automatically to process the huge amounts of data generated by eye tracking, en eliminate introducing errors with manual data processing.

Pernice and Nielsen (2009) recommend using gaze replays with six participants for qualitative eye tracking. Gaze replays enable the researcher to watch the test session video with the user's eye motion overlaid over a recording of the changing computer screen image. The user's eye is represented by a blue dot moving around the screen. Gaze replays are the most accurate method for analysing the information since the replay can be slowed down to really see everything the user looked at in the order in which they were doing it. However, they are very time consuming since the eye moves so quickly that segments frequently have to be slowed down and replayed to get an accurate idea of what happened (Pernice & Nielsen, 2009).

Heat maps and gaze plots can only be used when all participants follow the same path through an application. Therefore only gaze replays were used to investigate how participants used the tutorial, as each student followed his or her own path through the tutorial. After eye tracking, the participants were asked to draw variable diagrams in a retrospective comprehension test to give an indication of the comprehension or learning of the participant.

Data analysis

The main objective with the multiple-choice questionnaire included with the first assignment, was to investigate the effect of the tutorial on examination marks. As far as the data analysis was concerned, statistical analysis was used to investigate several factors that may affect students' performance, such as the biographical properties of students, their positive user experience and their use of tracing. The extent and manner of their tutorial use were investigated in relation to their examination marks. A trained statistician performed the analysis to ensure its validity. It should be noted that since the survey was adapted and expanded, more factors were investigated in the second cycle.

Statistical analysis has also been used to compare the examination results of the participants with the marks for questions on reading (tracing) program code, explaining program code and writing program code to determine whether the students' ability to read code (that is explain the purpose of code) and trace code had any effect on students' results. This was done to confirm that the findings from the BRACElet project that was used as the departing point for this study, applied to the participants in this study.

The live observations in the usability laboratory and the questionnaires completed after the observations were used to provide further insight into the results of the statistical analysis. Tracking the eye movements of participants using the tutorial provided knowledge of how students interact with the tutorial. This identified usability problems with regard to the layout of the tutorial, terminology used, students' comprehension of the material presented and their navigation through the tutorial. Analysing students' actions, menu selections, reactions and body language on the video recordings were combined with gaze replays, the retrospective comprehension test and the semi-structured, open-ended questionnaire students complete after the eye tracking, to expose usability problems with the tutorial. Improvements to the design could therefore be based on learner interaction and feedback.

Together, these insights were used to refine and adapt the tutorial for further use. During the second cycle, this was used as indications of whether refinement of the tutorial solved or improved usability problems with the tutorial. These insights were once again used to refine and adapt the tutorial for further use.

The findings from the data analysis during the first cycle are reported in Chapter 6 and the findings from the data analysis during the second cycle are reported in Chapter 7. These two chapters also report on how the data analysis was used to adapt and refine the tutorial for the next cycle in the study or for further use.

4.3.5.4 Phase 4: Reflection to produce 'design principles' and enhance solution implementation

During this phase the output of the design-based research effort, that is, the knowledge and products produced, are presented. The output consists of the following (Herrington et al., 2007):

- The theoretical contribution of the research in the form of design principles that can be used for further development and implementation decisions.
- The practical output, namely the designed artifact itself.
- Societal outputs in the form of professional development of participants.

The theoretical contribution takes the form of the framework of guidelines for using visualization in teaching programming. The framework of guidelines for using visualization in teaching programming compiled from the literature review in Chapter 5 was used as the starting point for the design of the tutorial. Lessons learnt and guidelines derived during the process of design and development of the tutorial, as well as in the subsequent cycles of refinement and testing, were documented to enhance the framework of guidelines and incorporated into the framework to refine it in Chapter 7.

In Chapter 8, the summary and conclusion, the success of the intervention is evaluated and the findings discussed to show the significance of the study. The findings from each of the previous phases were combined to answer the research questions and included reflections on the reasons for the findings. The tutorial is available on the following link:
http://osprey.unisa.ac.za/download/Disk/tuts/COS1512/Variable%20diagram%20application%20%28for%20downloading%29/. Click on Unisa.exe to download and execute it.

In Chapter 8 the researcher also reflects on the validity of the research and the societal outputs, including her professional development during the research.

4.3.6 Validating the research effort

The validity of a research effort entails three aspects (Leedy & Ormrod, 2005), namely –

- internal validity – the extent to which the researcher can conclude and defend cause and effect relationships among variables;
- external validity – the extent to the researcher can conclude that results can be generalised to a broader context or larger population; and
- general credibility and trustworthiness – the extent to which others perceive the findings to be convincing and of value.

Creswell and Plano Clark (2011) define validity in mixed methods research, as applying strategies that address potential issues in data collection, data analysis and interpretations that might affect the merging of the qualitative and quantitative components of the study and the conclusions drawn. The following validity issues required particular attention when integrating the quantitative and qualitative results in this study (Creswell & Plano Clark, 2011; Leedy & Ormrod, 2005):

- Samples for quantitative and qualitative aspects of the study had to be the same or sufficiently similar to justify comparison between the quantitative and qualitative data.
- The quantitative and qualitative data should have addressed the same or related topics and research question(s).
- Were the quantitative and qualitative data weighted equally in drawing conclusions? If not, what was the rationale for giving priority to one type of data over the other?
- Specific statements or artifacts from the qualitative element of the study had to be used to support or illustrate the quantitative results.
- Divergent findings between the quantitative and qualitative data had to be reasonably resolved by gathering more data, reanalyzing current data and evaluating procedures.
- The iterative cycles had to be related to each other.

As discussed in section 4.3.1.2 of this chapter, meticulous documentation; triangulation through multiple data sources and iterative cycles of implementation and analysis; as well as standardised measures had be used to ensure reliability of findings and measures. In addition the validity of data collection and analysis had to be ensured.

To ensure validity in the two cycles of data collection and analysis, the researcher had to adhere to methodological practices consistent with using questionnaires and observation with eye tracking to confirm the trustworthiness and credibility of claims (Barab & Squire, 2004). As mentioned before, a trained statistician did the statistical analysis to ensure its validity.

Possible threats to the validity of the statistical analysis include the following (Oates, 2006):

- Differences between the year-groups used in the two implementation cycles (internal validity).
- Events and changes in the Unisa ODL environment beyond the researcher's control (internal validity).
- Reactivity on the part of participants that wanted to help the researcher or to give a good impression, and so tried to respond by giving what they think were the 'correct' responses (internal validity).
- Too few participants that completed the questionnaires (external validity).

The researcher was the only person analysing the gaze replays for the eye-tracking participants. To counteract possible threats to the validity in this process at least 6 participants performing the same tasks, were used to provide triangulation of data, as recommended by Pernice and Nielsen (2009). Verbatim quotes from participants' feedback questionnaires were used to confirm findings. The researcher also had to constantly reflect on her own assumptions and the effect her presence might have had on the participants (Oates, 2006).

The next section addresses the ethical considerations applied in this study.

4.3.7 Ethical considerations

To comply with the Unisa research ethics policy, ethical clearance for this PhD study was obtained from the School of Computing Ethics Sub-Committee in the College of Science, Engineering and Technology at Unisa. The application for ethical clearance included screen shots of the tutorial; the questionnaires students were to complete to determine their use and user experience of the tutorial; and the informed consent form to be completed by students tested with eye tracking in the HCI laboratory at Unisa, as well as the questionnaire that students were to complete after the eye tracking tests. The letter confirming that ethical clearance was granted is included in Appendix A.

The work of the BRACElet project to understand the development of novice programmers and the role of tracing in this process was a motivation for this study. One of the guiding and ethical principles followed by the BRACElet project was that the study should not impact negatively on any student (Clear, Edwards et al., 2008; Whalley & Clear, 2007; Whalley & Lister, 2009; Whalley & Robbins, 2007). In this study, the researcher considered it important to follow the same principle. As a result, a control group in which students would not have had access to the tutorial, while the rest of the students did have access, could not be used. Instead factor analysis was done to determine the effect of a number of factors (described in Chapters 6 and 7) on students' final marks, including students' use of the tutorial. In preparation for this study, questions on tracing had been included in assignments and the examination.

4.4 Conclusion and summary

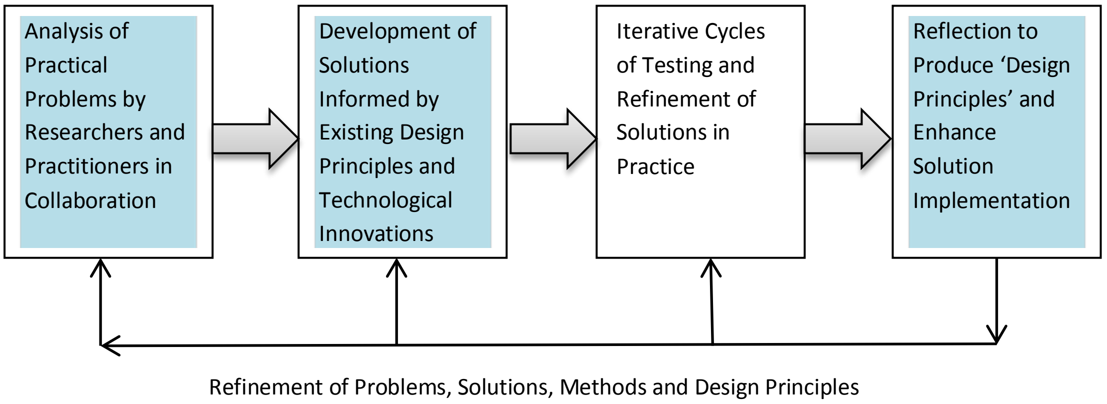
This chapter presented the research design and methodology used in this study. In section 4.2 the various aspects comprising a research design were discussed, and in section 4.3 the research design and methodology were described according to these aspects.

Section 4.3.1 provided an overview of design-based research, the research design used. The research problem and purpose of the research, including the research questions, were reiterated in section 4.3.2. Section 4.3.3 provided the justification for choosing pragmatism as the philosophical paradigm or approach for this research. The context, in which the research was conducted, is described in terms of the local context, the broader context and the researcher' own context, in section 4.3.4.

In section 4.3.5 Reeves' (2006) four phases of design-based research were used to elaborate on the methodology followed. The first of these four phases has already been addressed in Chapters 2 and 3 as well as in certain sections in this chapter. In section 4.3.6, validating the research effort was discussed. Section 4.3.7 addressed ethical considerations. In the next chapter the second of Reeves' (2006) four phases, namely the development of solutions informed by existing design principles and technological innovations, is described.

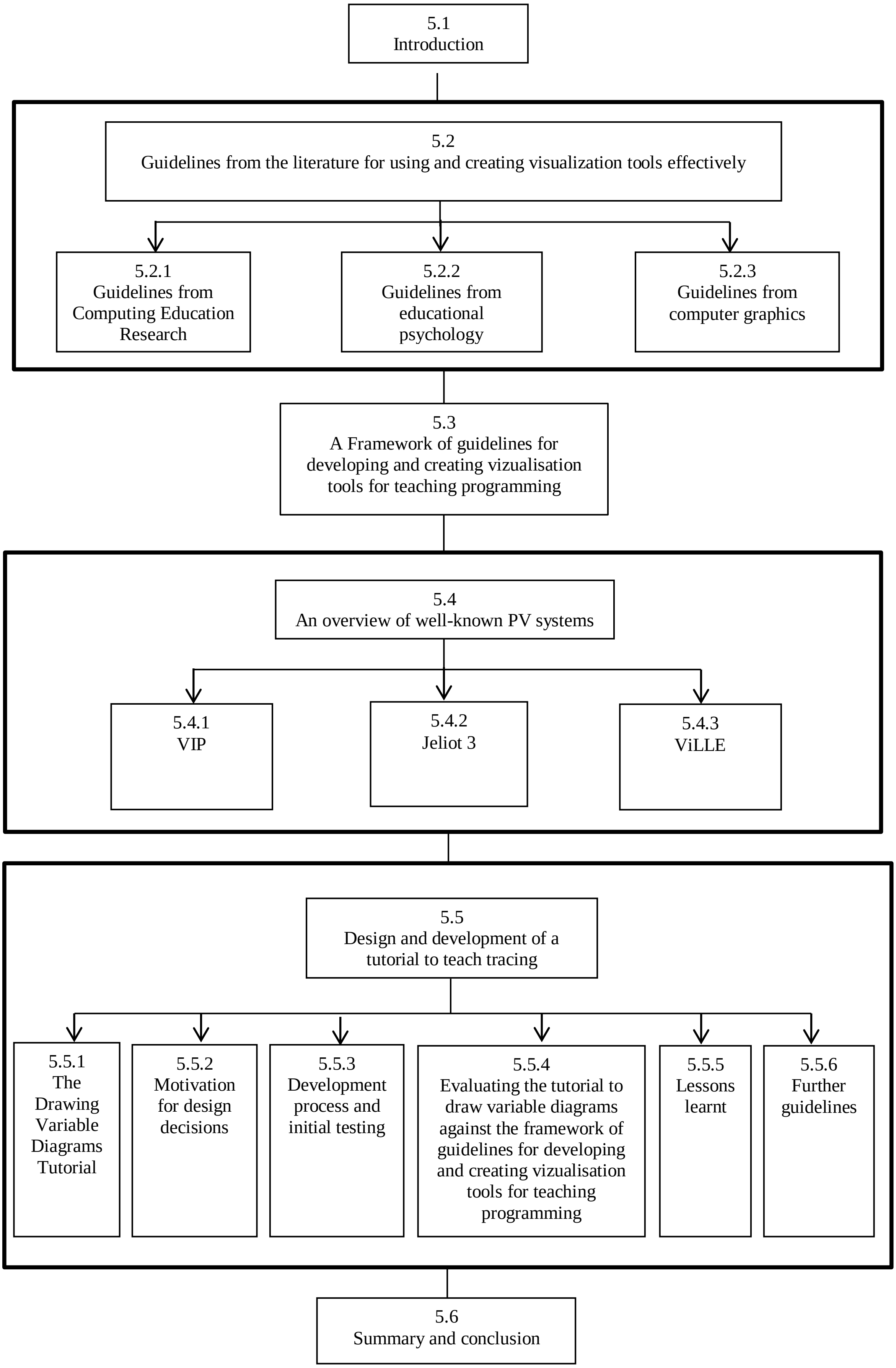
Design-based research phase covered in Chapter 5

Design-based research


Analysis of Practical Problems by Researchers and Practitioners in Collaboration
Development of Solutions Informed by Existing Design Principles and Technological Innovations
Iterative Cycles of Testing and Refinement of Solutions in Practice
Reflection to Produce 'Design Principles' and Enhance Solution Implementation
Refinement of Problems, Solutions, Methods and Design Principles

Phase	**Element**	**Position**
Phase of design-based research (Reeves, 2006)	*Topics/elements that need to be addressed*	*Position in this thesis*
PHASE 1: Analysis of practical problems by researchers and practitioners in collaboration	Statement of problem	Chapter 1, Section 1.3.1 Chapter 4, Section 4.3.2.1
	Consultation with researchers and practitioners	Chapter 4, Section 4.3.2.1 and section 4.3.4.3
	Research questions	Chapter 1, Section 1.3.3 Chapter 4, Section 4.3.2.3
	Literature review	Chapters 2 and 3, Section 5.2
PHASE 2: Development of solutions informed by existing design principles and technological innovations	Theoretical framework	Chapter 5, Section 5.2
	Development of draft principles to guide the design of the intervention	Chapter 5, Section 5.3
	Description of proposed intervention	Chapter 5, Section 5.5
PHASE 3: Iterative cycles of testing and refinement of solutions in practice	Implementation of intervention (First iteration) Participants Data collection Data analysis	Chapter 6
	Implementation of intervention (Second and further iterations) Participants Data collection Data analysis	Chapter 7
PHASE 4: Reflection to produce 'design principles' and enhance solution implementation	Design principles	Chapters 5, 6 and 7
	Designed artefact(s)	Available on course website
	Professional development	Chapter 8

Map of Chapter 5 (Development of the tutorial to teach tracing)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Chapter 5 Development of the tutorial to teach tracing

5.1 Introduction

This study addresses the low pass rate situation in a first-year programming module (COS1511) at Unisa, by providing the students with an interactive tutorial to teach them how to trace a computer program. In particular, students experience problems to understand and learn from text-based study material how to draw diagrams to trace program code. The literature review in Chapters 2 and 3 has shown the importance of tracing in learning to program. This chapter describes the development of the tutorial used to teach the students program tracing. It resembles a PV tool.

As discussed in the previous chapter, design-based research is used as research design for this study. The aim of the research was therefore two-fold, devising a practical intervention in the form of the tutorial as well as developing a framework of guidelines for using and creating visualizations or visualization tools to teach programming. The tutorial developed in this study is specifically adapted for use in an ODL environment.

The study is aligned to the four phases of design-based research according to Reeves (Reeves, 2006). As has been shown in Table 4.3 in Chapter 4, most of the first phase (analysis of practical problems by researchers and practitioners in collaboration), is addressed in various sections in Chapter 4. This includes the problem statement, input from researchers and practitioners, and the research questions. The final element in the first phase, the literature review, is covered almost completely in Chapters 2 and 3. This chapter presents the last component in the literature review in section 5.2, namely guidelines from literature for using and creating visualization tools effectively, as well as the rest of the second phase in design-based research (Reeves, 2006). This involved the development of a solution informed by existing design principles and technological innovation.

The guidelines from the literature for using and creating visualization tools effectively as described in section 5.2 were used to construct a framework of guidelines for using and creating visualizations and visualization tools to teach programming. This framework is presented in section 5.3 and acted as the theoretical framework to guide the design of the tutorial to teach tracing. The design and development of the tutorial itself, as well as its evaluation against the framework of guidelines, is described in section 5.4. This includes lessons learnt during the development and testing of the tutorial which led to further guidelines for developing PV tools. The summary and conclusion is presented in section 5.5.

5.2 Guidelines from the literature for using and creating visualization tools effectively

AV (algorithm visualization) refers to illustrating an algorithm in terms of its high-level operations to enhance understanding of its procedural behaviour (Hundhausen et al., 2002). PV (program visualization) on the other hand, visualizes the actual implemented code or data, showing the effect of each operation (Rößling et al., 2008). In 2007, Shaffer et al. (2007) claimed that despite a significant number of papers reporting on AVs, not much has been published on how to create pedagogically useful algorithm visualizations. Recently, however, the body of research on using AVs effectively is growing (Shaffer et al., 2011). Since PVs require much more effort to implement, the bulk of visualizations are AVs (Rößling et al., 2008), while most literature reviews also focus on AV. However, although fewer papers provide guidelines for effective PVs, since AV is so close to PV, many of the results in AV research can be applied to PV (Lahtinen, 2008).

This section presents guidelines from the literature for using and creating effective educational visualization tools from three research areas, namely CER, educational psychology and computer graphics. These general guidelines were used as a point of departure for developing the tutorial. Note that in the ODL environment at Unisa where students have to study on their own, some of these guidelines were not appropriate for use.

5.2.1 Guidelines from CER

Sorva, Karavirta and Malmi (2013:15:8) note that "Even a visualization that has been painstakingly crafted to be as lucid as possible may fail to aid learning in practice". In CER there seems to be general consensus that visualizations are only educationally effective if they actively engage learners in activities such as the following (Foutsitzis & Demetriadis, 2008; Hundhausen & Douglas, 2002; Hundhausen et al., 2002; Naps, Rößling et al., 2003; Pears, Seidman et al., 2007):

- Constructing their own input data sets.
- Making predictions regarding future visualization states.
- Programming the target algorithm.
- Answering strategic questions about the visualization.
- Constructing their own visualizations.

Other ways in which program and algorithm visualization (PAV) can engage students, are to encourage them to search for trends or structures; test a hypothesis through interaction; or by specifying a result that students should achieve by tinkering with the parameters of an algorithm (Foutsitzis & Demetriadis, 2008). Students can be asked to test their understanding through self-assessment exercises (Hundhausen & Douglas, 2002). Periodic questions posed by the PAV may serve the same purpose. Tickler questions (random pop-up questions in appropriate context without feedback) focus students' attention on specific issues and encourage self-explanation. Multiple-choice questions and questions that prevent the user from continuing without the correct answer can also be used (Foutsitzis & Demetriadis, 2008; Hansen, Narayanan & Hegarty, 2002; Naps, Rößling et al., 2003; Rößling et al., 2008).

To ensure that students accept a PAV tool and really engage with it, it should be integrated as part of the course material (Ben-Bassat Levy & Ben-Ari, 2007; Lahtinen, 2006; Lahtinen, Jarvinen & Melakoski-Vistbacka, 2007; Rößling, 2010). Furthermore, they should be properly guided in how to use it, as research has shown that this can lead to statistically significantly better learning results (Grissom et al., 2003; Laakso et al., 2008b). PAV should be used with discretion. Since the use of PAV tools can assist students with problems, but also have no value for students who already understand programming well, Lahtinen (2006) and Lahtinen, Ahoniemi and Salo (2007) recommend that students should be allowed to use PAV tools voluntarily.

Based on an empirical study and analysis, Stasko, Badre and Lewis (1993) report their insights on conditions when animations may be beneficial. They believe that to be most effective, teachers should provide comprehensive motivational instructions with animations. Animation displays should be accompanied by textual explanations of the various steps in the animation, and animations should be linked to specific instructional goals. Designers should perform user testing on each animation before using it for instruction. A rewind-replay capability should be included to allow users to backtrack and review operations. The authors also recommend that animation systems should support students to build their own animations (Stasko et al., 1993). All of these recommendations have been echoed and confirmed by follow-up research, as discussed below.

The Working Group on Visualization (Bergin, Brodie, Patiño-Martínez, McNally, Naps, Rodger, Wilson, Goldweber, Khuri & Jiménez-Peris, 1996) provides the following principles to keep in mind when designing a visualization tool:

- The primary goal when constructing a visualization should be to instruct and not to entertain. 'Tricks' to capture attention should be used to improve students' comprehension.
- Provide the user with a standard GUI to manipulate the tool, for example a GUI similar to a Windows environment with which the user is already familiar.
- Provide different views of the data, program or algorithm, for example. for a Quicksort algorithm the actual data in an array structure, a 'sticks' view where the length of a bar represents the magnitude of a value in the array, or the run-time stack and the recursive call tree.
- Provide the user with simultaneous identical views of different algorithms manipulating the same data, for instance when comparing algorithms, present the user with the same view of the two algorithms using the same data set, in different windows.

- Draw the user's attention to critical areas of the visualization, by using different colours for example.
- Use a text window to explain the visualization to ensure that the user understands it. This window should ideally be visible throughout the visualization.
- Provide a high degree of user interactive control to allow the user to pan, zoom, pause, speed-up, slow-down and re-wind during the visualization.
- The best visualizations will require high-end display devices to allow different views of the same algorithm, a simultaneous identical view of different algorithms as well as a text window for explanations.

The Working Group on Improving the Educational Impact of Algorithm Visualization (Naps, Röβling et al., 2003) describes the following set of best practices, based on experience, developed since the '80's:

- Provide resources that help learners interpret the graphical representation that maps the visualization to the underlying algorithm by explaining it with text or narration, or reinforce the relationship with instructional time during the course.
- Adapt to the knowledge level of the user, for example use a less complicated system for novices.
- Provide multiple views with windows for both pseudocode and program animation, or program animation and algorithm animation for instance.
- Include performance information that shows the algorithm's efficiency.
- Include the execution history so that learners can see previous steps.
- Support flexible execution control, for example by allowing the user to move both forward and backwards and stop and pause.
- Support learner-built visualizations that allow users to build their own visualizations.
- Support custom input data sets so that users can explore the visualization with different data sets.
- Support dynamic questions by periodically asking pop-up questions (ticklers) or questions that prevent the user from continuing without correct answers.
- Support dynamic feedback on the learner's activities in the system.
- Complement visualizations with explanations, for instance with a coordinated text window or audio track, and integrating it into the course.

Several of the recommendations by these two working groups correspond, namely proving multiple views, flexible execution control and providing explanations.

Röβling and Naps (2002) identified a set of pedagogical requirements for an AV to be an effective learning tool. They subsequently combined two AV systems, ANIMAL (Röβling & Freisleben, 2002) and JHAVÉ (Naps, 2005) to produce a prototype that satisfies these requirements. Some of these requirements correspond with the following recommendations by the two working groups discussed above (Bergin et al., 1996; Naps, Röβling et al., 2003):

- It should reliably reach a large target audience. Accordingly, the system's platform should be chosen to allow the widest possible target audience.
- It should be a general-purpose system that offers a common interface to a multitude of animations, to make integration into a course easier.
- Users should be allowed to provide input to the algorithm. However, data input facilities should be carefully constructed to focus learners' attention on the intended type of understanding.
- Users should be able to rewind an algorithm's execution, as well as to backtrack step-by-step to increase understanding.
- A structural view of the algorithm's main parts should allow the student to move directly to a specific key point in the animation without a search or having to cover steps that they understand.
- Interactive questions that require the student to predict the next step in the visualization to ensure the student follows it (interactive prediction) should be included.
- The AV should be integrated with a database for course management reasons, to allow tracking students' responses. The report from a working group on this aspect is described by Röβling et al. (2008).
- Hypertext explanations of the visual display should be included to assist students in understanding the mapping of the AV's abstractions to the system's display of the abstractions.
- The AV should support both smooth motion, as well as the option to view it in discrete snapshots to help users detect changes. Rewinding should also allow for both smooth motion and viewing in discrete steps.

Saraiya, Shaffer, McCrickard and North (2004) also identified the following list of key features that they hypothesize might be characteristic of good AVs:

- Ease of use – a pedagogically useful AV should have no usability and reliability concerns.
- Appropriate feedback should be based on the assumed background knowledge of users, which should be made clear.
- All state changes caused by the algorithm acting on some data structure, should be shown.
- Window management should allow all windows to be visible when the AV starts and might allow users to resize or reposition windows to suit the user.

- Multiple views of the AV, for example both the logical and the physical view of a data structure as well as the distinction and connection between these views should be shown.
- Users should be able to control the speed of the presentation to provide different rates to progress through the AV as well as to re-run and step backwards through a visualization.
- Good test cases should be provided in the form of canned examples, but users should also be allowed to enter their own examples and data input.
- Clear pseudocode should be provided to help the user relate state changes directly to algorithm's progress.

Several of the characteristics identified by Saraiya et al. (2004) correspond with those indicated by Bergin et al. (1996), Naps, Röβling et al. (2003) and Röβling and Naps (2002). Characteristics recommended by all of them, are providing multiple views of the visualization and allowing user control over the execution of the AV. Saraiya et al. (2004) conducted two experiments to verify the effect of their hypothesis. Some of the characteristics in their hypothesis were verified, while others did not hold. They found as follows (Saraiya et al., 2004):

- Allowing a user to step through the AV improves the pedagogical value more than allowing the user to control the rate at which the AV runs the presentation.
- Canned data sets that cover the important cases in an algorithm significantly increase the pedagogical value of an AV, while allowing users to enter their own data sets do not provide significant pedagogical value, since they do not have the ability to choose good test cases.
- Participants provided with a pseudocode display and a question guide (a series of questions meant to guide users through AV and force them to engage with the content of the AV), spend substantially more time with the AV as compared to using simple AVs without these features. However, neither the pseudocode display nor the question guide appears to have had significant pedagogical benefit. Also, an analysis of learning time versus performance showed that a larger learning time does not mean participants understand the algorithm any better. This implies that providing the right set of features could reduce learning time, while using more features may result in increase in learning time with little pedagogical benefit. This finding contradicts (Hundhausen et al., 2002) who suggests that more time spent with AV translates into more learning.

Based on a literature review and analysis of existing algorithm animations, Yeh, Greyling and Cilliers (2006) offer the following list of requirements for the design of pedagogically effective algorithm animations, of which nearly all of them overlap with recommendations from other researchers:

- Allow speed control of the algorithm animation.
- Accept user input data for the algorithm.
- Allow step-by-step execution of the algorithm animation.

- Provide facilities to allow students to construct animations.
- Include support for smooth motion.
- Include capabilities for comparative algorithm analysis.
- Provide multiple views of an algorithm.
- Include additional instructional material.
- Provide a general purpose framework.

The AV known as Hypermedia Algorithm Visualization (HalVis) is the result of a research program to develop educationally effective algorithm visualizations (Hansen et al., 2002). The key features of HalVis provide five guidelines for effective algorithm animations. These are based on the following major characteristics for learner-centred design:

- A context for learning – HalVis embeds the animation in a hypermedia environment that provides a context for learning with textual descriptions, static diagrams and interactive examples. The focus is on providing relevant and appropriate information to achieve specific learning objectives.
- Scaffolding – An animated analogy is presented in the very first view of the algorithm (for example illustrating merge sort by sorting a deck of cards). The analogy serves as scaffolding to support learning.
- Multiple and multimodal representations – Three distinct views of the animation are used to demonstrate the algorithm behaviour, namely the analogy, a micro view with a small data set, and a macro view with a large data set.
- A flexible interface for the learner – The algorithm animation is presented in discrete segments supplemented with explanations of the actions. Students may then pause according to their needs. They may also provide their own data or select between different sets of data. Together this provides a flexible interface.
- Incorporating interactive devices to engage and motivate the learner – Student interaction is encouraged with prompts to explore the different views and data sets provided, as well as periodic questions. Questions are random pop-up ticklers in appropriate context without feedback to stimulate self-explanation, as well as MCQs at breakpoints between modules of the visualization that provide immediate feedback.

In addition, the report by Hansen et al. (2002) on HalVis provides the following guidelines extracted from other successful animations, a number of which has been mentioned before:

- The animation should be well-paced.
- Algorithmic actions should be highlighted with good use of colour.
- A brief textual introduction should be included.
- Pseudocode for the algorithm should also be included.

- Pseudocode lines should be highlighted synchronously as the animation executes.

McNally, Naps, Furcy, Grissom and Trefftz (2007) developed AVsupport, a suite of Java support classes that enables creators of visualizations to rapidly construct pedagogically effective algorithm visualizations. AVsupport is based on a subset of features that educational research has indicated is required for real learning by users of animations. This subset includes the following:

- Accompanying text to explain the algorithmic context for the graphics being watched, to the learner. AVsupport offers textual support in the form of standard HTML documents in which the algorithm is described conceptually and pseudocode synchronised with the states of the algorithm being graphically displayed.
- Variety should allow the learner to view repeated, but differing visualizations of the same algorithm. This can be achieved by allowing the learner to provide different inputs to the algorithm.
- Interactive questioning asks the learners questions that will force them to stop and think about what they are viewing. If interactive feedback is provided, this will show them how well they understand the algorithm.
- Ability to move backward and forward through the visualization: An animation should be seen as a sequence of snapshots of the state of the algorithm at various points in its execution. Therefore, if learners become confused somewhere along the sequence, they must be able to selectively backtrack up to where they became lost.

Based on three qualitative studies among university and high school students about their use of the PV tool ViLLE, Kaila et al. (2011) point out essential features for PV tools. As research has shown repeatedly, the tool should activate and engage students, for example with questions (Ben-Ari et al., 2011; Grissom et al., 2003; Isohanni & Knobelsdorf, 2011; Kaila et al., 2009; Laakso et al., 2009; Urquiza-Fuentes & Velázquez-Iturbide, 2009a). Flexible controls, especially the ability to move backwards in execution, are highly valued. This has also been suggested a number of times in previous research results (McNally et al., 2007; Röβling & Naps, 2002; Saraiya et al., 2004). Variable states should be shown clearly. Textual explanations in natural language, synchronised with program state information, should be included.

5.2.2 Guidelines from educational psychology

Some PAV researchers provide recommendations derived from educational psychology. These guidelines take the cognitive and perceptive demands of animation, as well as learning theories such as dual coding and cognitive load into consideration.

Taylor and Pountney (2009) conducted experiments with UK undergraduate computing students to compare the perceived usefulness of animated and static learning materials. In these experiments the animations displayed the material appearing or moving over a period of time, while the corresponding static version displayed all the material simultaneously. The researchers' conclusion was that animations in the form of a visual demonstration are more useful than static learning material to show how a computing process or sequence of actions develops (Taylor & Pountney, 2009). They also extracted the following number of guidelines for animation from the educational psychology literature: Animations for teaching purposes should be of small scope, and only incorporated into learning activities when the characteristics of animation are consistent with the learning task. In some situations multiple discrete diagrams may serve the purpose better than animations since this can allow comparisons and repeated inspection of details. Animations should not be too complex. Dual coding, where visual and auditory presentations are used together, may enhance comprehension. If dual coding is used, the animation and the narration should occur simultaneously, and the textual explanation should be near to the animation on the screen. Attention should be drawn to important aspects of the animation to produce the required effect (Taylor & Pountney, 2009).

Chan and Black (2005:934) argue that "to develop effective animation that encourages learning, we need to consider individuals' internal visualization processes and their mental model development, i.e., the learners' limited working memory capacity; the perceptual and cognitive demands that animation may impose on them, especially novices; and the support learners may need to perceive and understand the visible as well as the 'hidden' functional relationships among components within complex systems". The authors believe that the effectiveness of a presentation format depends on the degree to which it matches the learners' cognitive and comprehension processes (Chan & Black, 2005). To overcome the perceptive and cognitive demands of animation, they recommend *direct-manipulation animation* (DMA). With DMA learners interact directly with the navigation controls (such as buttons and sliders) of an animation to determine the direction of their viewing themselves. This allows them to control their viewing sequence in such a way that they can visualize how a change in one parameter affects other parameters in the dynamic system. DMA corresponds with a guideline that crops up repeated in the guidelines from CER, namely allowing users to backtrack and move forwards at will, but it provides the theory that explains why this is effective.

Chan and Black (2005) recommend some design principles to enhance human computer interaction (HCI) and encourage effective learning. In terms of these design principles the importance of usability testing for animations is emphasised as follows:

- The decision to use a static or dynamic presentation of learning material should be based on pedagogical grounds, that is, what will best support learners in mastering the study material. (This corresponds with one of Taylor and Pountey's (2009) recommendations).
- Learners need sufficient time and mental resources to process and understand the relationships between various components in the animation. (DMA supports this).

- A user-centred design is important. Consistent locations for buttons, sliders and switches will minimise perceptual and cognitive demands on learners. Providing alternative interaction methods such as sliders, or arrows on the screen to advance or backtrack, or keyboard arrows, can accommodate different navigation styles or learning preferences.

Chan and Black's (2005) recommendations tie in with two principles formulated by Tversky, Morrison and Betrancourt (2002) that specify the conditions under which animation may be effective, namely the congruence principle and the apprehension principle, as follows:

- The *congruence* principle states that "the structure and content of the external representation should correspond to the desired structure and content of the internal representation" (Tversky et al.:257). The animation should therefore present the process or procedure in the same way and order that people visualize it.
- The *apprehension* principle states that "the structure and content of the external presentation should be readily and accurately perceived and comprehended" (Tversky et al., 2002:258). This means that the animation must be slow and clear enough to allow learners to perceive changes and to understand the changes in the relations between the different parts and the sequence of events.

Wouters, Paas and Merriënboer (2008) offer guidelines for designing effective animation from the perspective of educational design, based on cognitive load theory. Cognitive load theory is "a theory that emphasizes working memory constraints as determinants of instructional design effectiveness" (Sweller, van Merriënboer & Paas, 1998:251). Learning requires information processing that involves two structures in the human cognitive architecture, working memory and long-term memory. Working memory has a limited processing capacity, while long-term memory has a virtually unlimited capacity that can enhance working memory's processing capacity with schemas.

Cognitive load theory posits that information can impose a cognitive load on working memory in the following three respects (Sweller et al., 1998; Wouters et al., 2008):

- Intrinsic cognitive load depends on the interactivity of the subject matter, that is, the complexity of the elements composing the information and the way they interact with each other.
- Extraneous cognitive load depends on the way the information is presented. Poorly designed educational material increases the extraneous cognitive load.
- Germane, or effective, cognitive load, is imposed when the information is presented in such a way that learning is encouraged by facilitating the construction and/or automation of cognitive schemas.

Subject matter with a large number of interactive elements is considered to be more difficult to master than material with fewer elements and/or a low interactivity (De Jong, 2010). The tight integration of concepts in a programming language is an indication of the high intrinsic cognitive load (Robins, 2010). The difficulty of the curriculum and course contents has also been listed as one of the reasons why novices fail to learn to program (Jenkins, 2002; Kinnunen & Malmi, 2008; Kinnunen et al., 2007; Miliszewska & Tan, 2007; Pears, East et al., 2007).

The three types of cognitive load are not isolated but combine into a load which cannot exceed the available cognitive capacity, with the effect that a high load of one component comes at the cost of another component. Therefore, to ensure effective learning, either the extraneous cognitive load or, in the case of (very) complex material, both the extraneous cognitive load and the intrinsic cognitive load should be reduced to increase the germane cognitive load (Wouters et al., 2008).

Wouters et al. (2008) offer the following guidelines to decrease intrinsic cognitive load by reducing or managing the interactivity of the learning material:

- Scaffold learning with a sequence of simple-to-complex whole tasks. A whole task requires the integration of different skills and knowledge. Start with relatively simple whole tasks to allow learners to construct and automate schemas with low element interactivity and then gradually increase the complexity.
- Use pre-training to first present isolated components before the interaction between these components is instructed.

Guidelines to decrease the extraneous cognitive load, that is, to reduce activities that impede learning, are the following (Wouters et al., 2008):

- Use pacing, which allows learners to control the tempo of presentation according to their own cognitive needs. This concurs with Tversky et al.'s (2002) apprehension principle.
- Use segmentation by dividing animations into several segments in which each segment presents an important part of a procedure or process.
- Apply the modality principle. Modality refers to the sensory mode in which verbal information is presented: written or spoken. The modality principle suggests that textual explanations in animations should be presented in spoken format, as this allows more information to be processed visually. However, if the speaker has a foreign accent, this may have a negative effect, since the additional effort to decipher the accent adds to the cognitive load (Mayer, Sobko & Mautone, 2003). Also, when learners have control over the pacing of the animation, written explanatory text is more effective than spoken explanatory text, since this allows the student more time to study the information. It is also much easier to move forwards and backwards through written text than through spoken texts, because the linearity

of the spoken text makes it more difficult to follow when scanning it through (Tabbers, Martens & Merriënboer, 2004).

- Use the contiguity principle. The contiguity principle states that verbal explanations in animations should be presented contiguously in time and textual explanation in the same space as the illustrative material, so that the explanation and the pictorial information are active simultaneously in working memory. This should exclude the split-attention effect. The split-attention effect occurs when one source of information must be held in working memory while searching for another, because the two sources of information have to been integrated before it can be understood (Sweller et al., 1998).
- Use signalling, or cueing to present cues to assist the learner in selecting and organising the instructional material. This could take various forms, such as underlining words, or using arrows to focus attention on a specific part of the animation. Signalling assists meaningful learning because it guides attention to relevant information and facilitates the efficiency of a visual search for the necessary information (Ozcelik, Arslan-Ari & Cagiltay, 2010).

The following guidelines, suggested by Wouters et al. (2008) to increase germane cognitive load, are intended to prompt learners in engaging in active processing of the learning material:

- Use expectancy-driven methods that require learners to predict the next step in a process in the animation. This encourages self-explanation that will assist integrating newly acquired knowledge with prior knowledge. Other researchers also recommend questions that ask learners to predict the next step as a way to engage learners with animation (Foutsitzis & Demetriadis, 2008; Hundhausen & Douglas, 2002; Hundhausen et al., 2002; Naps, Röβling et al., 2003; Pears, East et al., 2007).
- Use sub-goaling to prompt learners to group coherent steps of a procedure into a meaningful sub-goal in the animation.
- Ask learners to imagine procedures and concepts that are used in the animation, since studies have shown that imagining skills before performing them leads to better performance (Cooper, Tindall-Ford, Chandler & Sweller, 2001; Leahy & Sweller, 2004).
- Use variability by presenting problems that vary in relevant features so that leaners can develop appropriate schemas by distinguishing between the relevant and irrelevant features.

The effectiveness of Wouters et al.'s (2008) guidelines depends on several mediating factors, notably learners' prior knowledge, spatial ability, motivation and the age of the learner. Animations intended for novices may have no benefits for students with prior knowledge, as pointed out previously by (Lahtinen, 2006; Lahtinen, Ahoniema & Salo, 2007). Learners with high spatial ability benefit more from animations with verbal explanations than learners with low spatial ability. The pattern of cognitive load may be affected by motivation and self-efficacy. Also, the efficiency of working memory deteriorates with age. Design guidelines might also interact, for instance when pacing is used, modality should be adapted since learner pacing seems to cancel the advantage of verbal over written explanations. On the other hand, combinations of guidelines, such as signalling and modality, might be particularly effective (Wouters et al., 2008).

Mayer and Moreno (2002) present seven design principles ensuing from a research program on multimedia learning at University of California, Santa Barbara. Multimedia instruction exposes learners to material in both verbal (on-screen text or narration) and visual (static photos or illustrations, and video or animation) format. Mayer and Moreno's design principles are grounded in the cognitive theory of multimedia learning. The cognitive theory of multimedia learning is based on the following (Sorva, Karavirta & Malmi, 2013) three assumptions:

- The *dual-channel* assumption believes that people have separate channels for processing visual/pictorial representations and auditory/verbal representations.
- The *limited capacity* assumption presumes that each channel can only process a limited amount of information at any one time. This corresponds to the limited capacity of working memory in cognitive load theory.

Meaningful learning requires *active processing*, that only occurs when the learner engages in cognitive processes such as extracting relevant material, organising it into a coherent representation and integrating it with prior knowledge. Active processing brings to mind Naps' (2000) Engagement Taxonomy, as well as the research that emphasises the importance of engagement in order to learn from AV or PV. Figure 5.1 provides a visual summary of the cognitive theory of multimedia learning. Narration enters through the ears, the learner chooses some words for further processing in the verbal channel that organises it in a cause-and-effect chain, and integrates it with the information from the visual channel as well as prior knowledge. Animation enters through the eyes, the learner chooses some images for further processing in the visual channel, organises it into a cause-and-effect chain, and integrates it with the verbal information and prior knowledge. The theory postulates that integration is most likely to occur when the corresponding pictorial and verbal representations are in working memory at the same time. Accordingly, meaningful learning will be encouraged under

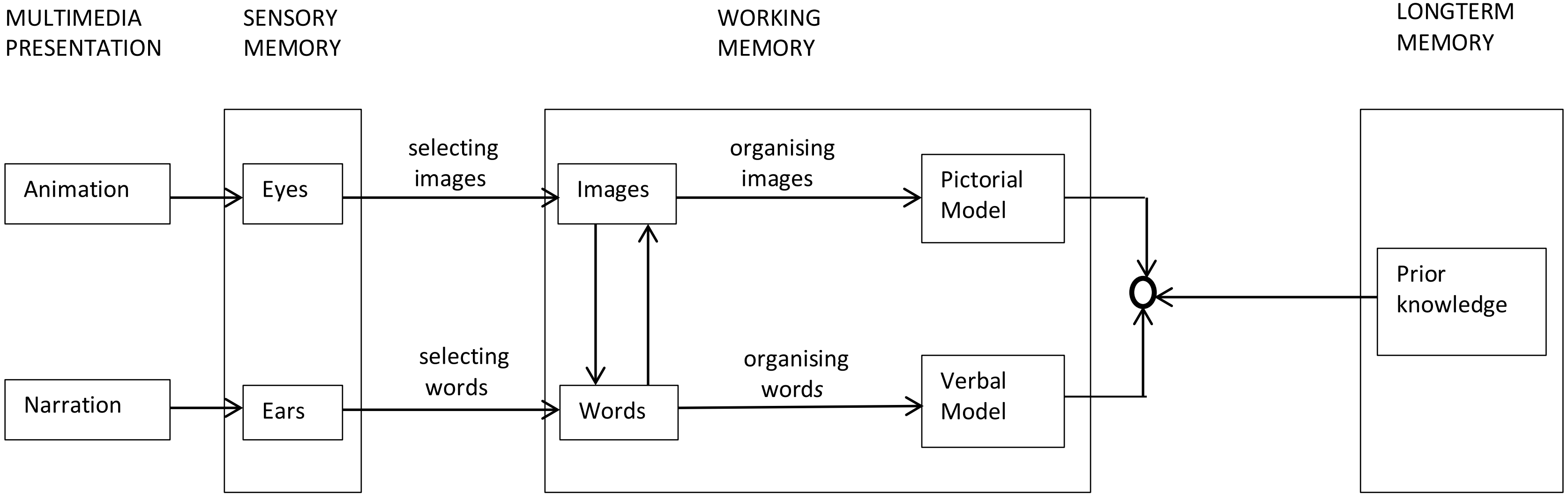


Figure 5.1 The cognitive theory of multimedia learning (2002)

instructional conditions that present pictorial and verbal information simultaneously (Mayer & Moreno, 2002).

The seven design principles resulting from the cognitive theory of multimedia learning are the following (Mayer & Moreno, 2002):

- The multimedia principle states that students learn better from both narration and animation than from narration alone, when the learner has to create the mental picture himself.
- The spatial contiguity principle asserts that on-screen text should be presented near to the part of the animation that it describes, to prevent wasting cognitive capacity on searching for the corresponding animation section.
- According to the temporal contiguity principle, learners make better connections when corresponding narration and animation are presented simultaneously.
- The coherence principle states that extraneous material (words, sounds, video, and pictures) should be excluded to prevent wasting cognitive resources on irrelevant material.
- The modality principle maintains that learners learn better from animation and narration, than from animation and on-screen text, since the visual channel is less likely to be overloaded. That should provide more opportunity to build connections between corresponding words and pictures.
- The redundancy principle asserts that learners learn better from animation and narration than from animation, narration and on-screen text. It is based on the same rationale as the modality principle.
- According to the personalisation principle, learners learn better from animation and narration when the narration is in conversational tone (using 'I' and 'you') since they are more involved and then work harder to understand the explanation.

Mayer and Moreno's (2002) contiguity principles and the modality principle correspond with Wouters et al.'s (2008) guidelines to decrease cognitive load. However, there is some evidence that the modality and contiguity principles have to be applied with caution in the development of a tutorial to teach novice programming students to trace.

With regard to the modality principle, the following research results have to be taken into account: If self-paced animation is used, as has been repeatedly recommended, visual text is more effective than spoken text, while it is also easier to move forwards and backwards through written text than through spoken text (Tabbers et al., 2004).

Research regarding learners' spatial ability should be taken into account when the contiguity principle is applied, since the contiguity principle is affected by learners' spatial ability. Mayer and Sims (1994:392) define spatial visualization as "the ability to mentally rotate or fold objects in two or three dimensions and to imagine the changing configuration of objects that would result from such manipulations". This ability is for example involved in building puzzles. The researchers examined the way in which the spatial ability of learners inexperienced in a domain, may affect their learning about a mechanical or biological system in that domain (Mayer & Sims, 1994:392). They found that concurrent presentation of verbal and visual information benefits mainly learners with a high spatial ability, since they have a better ability to build mental connections between the verbal and visual representations. Wouters et al. (2008) confirm that learners with high spatial ability benefit more than learners with low spatial ability from animations with verbal explanations. Cox, Fisher and O'Brien (2005:93) describe program comprehension as "the process of generating a cognitive map from the program source-code to a set of application domain concepts". Program code, then represents an abstract space that has to be navigated with the same cognitive strategies as used in natural environments. Jones and Burnett (2007) in turn found a strong positive correlation between students' spatial ability and their results in programming modules, with much lower correlations between their spatial ability and non-programming modules. This seems to suggest that students with lower spatial ability struggle more with programming subjects. They also found that students with a low spatial ability use less effective navigational strategies when attempting to comprehend code (Jones & Burnett, 2007). Therefore, it seems as if using verbal explanations in animation, even if the contiguity principle is applied, might be to the disadvantage of weak programming students.

In the design and development of an animation to teach tracing, each of the above guidelines, and in particular the modality and contiguity principles, should be considered carefully to determine whether it would benefit the students for whom it is intended.

5.2.3 Guidelines from computer graphics

Khuri (2001) has extracted important practical guidelines from the field of computer graphics for AV design and effective educational displays in algorithm animation. He stresses the importance of an analysis of the users, their needs, their tasks, the scope of the package and the resources available to developers. In this regard the following should be taken into account (Khuri, 2001):

- No AV can cater for all possible users. Novices need much more guidance in mapping the visualization to the program, as well as help in how to use the AV system, than experienced users. Short quizzes can help them understand the material. Experienced users, on the other hand, may want to integrate their own programs into the system.
- The content of the AV should be selected according to its intended purpose, and an assessment should be made to ensure that AV is the most effective way to present the information.

- The situations where the visualization will be used also influence its design. Visualizations intended for self-study need much more explanatory cues than one that will be used in a classroom situation.
- Care should be taken in deciding which information should be presented and how it should be done. An appropriate set of conventions in the form of the shape, size, colour, texture, sound and arrangement of objects to represent different information, should be developed and applied consistently.
- The designer should also set boundaries for the visualization, for example in the range and/or format of input allowed.

Khuri (2001) also provides some guidelines and techniques for the visual representation of information about programs. In particular, he discusses the display layout, using colour, sound, selecting input data and providing interactivity as follows:

- To prevent the display area from being cluttered, it should be divided into functional areas that are consistently used for the different types of information. Important information should be placed near the top left, since eye-motion studies (in Western society) show that a human being's gaze goes to the upper-left of a rectangular display and then moves clockwise. Multiple views of the same algorithm should be used judiciously to prevent information overload.
- Although people do not learn more from colour displays than from black and white displays, colour helps people to remember and is more enjoyable. A maximum of five colours, and preferably four only for novices, should be used to allow more short-term memory for information processing. Foveal (centre) and peripheral colours should be used appropriately, for example, blue is suitable for large backgrounds, while red and green should be used in the centre of the visual field. Strong contrasts of colours on the opposite of the colour wheel should be avoided since this produces vibrations, illusions of shadows and afterimages. Familiar colour coding such as red for stop or danger should be used. The same colour should be used consistently for related elements to assist conceptual comprehension without verbal clues. Bright colours should be used to draw attention. Colour can save screen space by for example using a small area changing in colour to indicate progress, rather than a bar or line.
- Non-speech sound can be used to draw the user's attention to an event. Since this can easily be an irritating feature, a flexible easily accessible user-configuration component should be included to allow users to specify the sound for each event and switching it on or off. Documentation, online training and examples should be given to prepare users for using this feature. The number of sounds should be restricted, since there is a threshold for the number of sounds that can be learned and remembered.

- In selecting input data, it is better to start with smaller sets and allow for larger sets for users who understand the visualization. Possible erroneous input situations should be taken into account.
- The degree, methods and forms of interaction will be determined by the tasks users have to accomplish when using the visualization. If the system is intended for exploratory purposes, the interaction should encourage the user's search for structures, trends or testing a hypothesis. Students may test their understanding through self-assessment exercises such as periodic tickler questions or questions that need to be answered before the animation proceeds. The interaction mechanism should be simple and forgiving. The designer should therefore take care to reduce the possibility of errors. An option is to allow reversal of actions, such as providing an 'undo' or 'redo' facility.

In the next section a framework of guidelines for developing and creating visualizations for teaching programming is offered.

5.3 A Framework of guidelines for developing and creating visualization tools for teaching programming

The framework of guidelines for developing and creating visualizations for teaching programming represents the theoretical contribution of this study. It consists of a series of guidelines, where possible, enhanced with one or more reasons or explanations for the guidelines as well as some considerations that need to be taken into account when applying the guideline. The guidelines, reasons and explanations, as well as the considerations were extracted from the literature covered in section 5.2. The field of educational psychology provided an especially rich source of reasons or explanations and considerations to be taken into account.

Several of the guidelines appear in all three areas covered by the literature review. Corresponding guidelines that appear in two or more areas have been synthesized into one guideline. Where possible, one or more reasons or explanations for using the guideline as explicated in the literature are included. Considerations to be taken into account when applying the guideline, again extracted from the literature, are also offered. The framework itself is presented in Table 5.1, with the numbered guidelines in the first column, reasons or explanations for using the guideline in the second column and considerations to be taken into account when applying the guideline in the third column. To improve readability, no references are shown in Table 5.1.

However, the framework with references included is also offered in Table F.1 in Appendix F. In Table F.1 each guideline is followed by the reference(s) that support it in the second column. In the third column reasons for using the guideline are offered, and in the fourth column considerations to be taken into account when applying the guideline, are listed. Each reason or explanation and consideration is also backed by the references concerned. Since these references are from three different fields, namely computing education, education psychology and computer graphics, the background of each reference in Table F.1 is shaded to indicate the field where it has been cited. References from CER are shaded in blue, references from educational psychology in pink, and references from computer graphics in purple.

Table F.1 also contains two additional guidelines namely guidelines 27 and 28, as well as expansions to guidelines 6, 10, 11, 16, 17 and 23 which resulted from the research effort. The additional guidelines and expanded guidelines are discussed in section 7.7 and shaded in green.

In the next section a description of the design and development of the tutorial to teach tracing is given. This include design decisions and the motivations for it, based on the framework of guidelines, a description of the tutorial itself, its development and testing and lessons learnt during this process.

Table 5.1 A Framework of guidelines for developing and creating visualizations for teaching programming

Guideline	Reason/explanation	Considerations/Comments
1. Actively engage learners with –	Meaningful learning requires *active processing*, that only occurs when the learner engages in cognitive processes such as extracting relevant material, organising it into a coherent representation and integrating it with prior knowledge. Prompting learners to engage in active processing of the learning material increase germane cognitive load, which encourages learning by facilitating the construction or automation of cognitive schemas. In addition, prompts to explore the different views and data sets provided, as well as periodic questions, not only engage learners, but can also motivate them.	The degree, methods and forms of interaction will be determined by the tasks users have to accomplish when using the visualization.
1.1 Constructing learners' own input data sets.	Presenting problems that vary in relevant features allow learners to develop appropriate schemas by distinguishing between the relevant and irrelevant features. Variety can be achieved by allowing the learner to provide different inputs to the algorithm so that the learner views repeated, but differing, visualizations of the same algorithm. If the algorithm animation is presented in discrete segments supplemented with explanations of the actions, so that students may pause according to their needs, while they may also provide their own data or select between different sets of data, a flexible interface is provided for the learner.	Data input facilities should be carefully constructed to focus learners' attention on the intended type of understanding. The designer should set boundaries for the visualization, for example in the range and/or format of input allowed. In selecting input data, it is better to start with smaller sets and allow for larger sets for users who understand the visualization. Possible erroneous input situations should be taken into account. Canned data sets that cover the important cases in an algorithm significantly increases the pedagogical value of an AV, while allowing users to enter their own data sets does not provide significant pedagogical value, since they do not have the ability to choose good test cases.
1.2 Programming the target algorithm/ constructing through learners' own visualizations.	Experienced users may want to integrate their own programs into the system.	
1.3 Making predictions regarding future visualization states.	Expectancy-driven methods that require learners to predict the next step in a process in the animations encourage self-explanation that will assist integrating newly acquired knowledge within prior knowledge.	
1.4 Answering strategic questions about the visualization, for instance searching for trends or	If the system is intended for exploratory purposes, the interaction should encourage the user's search for	

Guideline	Reason/explanation	Considerations/Comments
structures; testing a hypothesis through interaction; or specifying a result that students should achieve by tinkering with the parameters of an algorithm.	structures, trends or testing a hypothesis.	
1.5 Answering self-assessment exercises in the form of periodic questions, for example tickler and multiple choice questions, or questions that prevent the user from continuing without correct answers.	Students may test their understanding through self-assessment exercises such as periodic tickler questions or questions that need to be answered before the animation proceed, because interactive questioning forces them to stop and think about what they are viewing. Random pop-up tickler questions in appropriate context without feedback stimulate self-explanation. Interactive feedback will show students how well they understand the algorithm, while short quizzes can also help novices understand the material.	Multiple choice questions at breakpoints between modules of the visualization should provide immediate feedback. The interaction mechanism should be simple and forgiving. The designer should therefore take care to reduce the possibility of errors. An option is to allow reversal of actions, such as providing an 'undo' or 'redo' facility.
1.6 Using sub-goaling to prompt learners to group coherent steps of a procedure into a meaningful sub-goal in the animation.		
1.7 Asking learners to imagine procedures and concepts that are used in the animation.	Studies have shown that imagining skills before performing them, leads to better performance.	
1.8 Supporting dynamic feedback on the learner's activities in the system.		
2. Integrate visualizations into the course material.	Integrate the PAV tool with the study material to ensure that students accept and engage with it.	Allow students to use PAV voluntarily, since it can assist students with problems, but also have no value for students who already understand programming well. Animations should be linked to specific instructional goals, with relevant and appropriate information to achieve specific learning. The content of the AV should therefore be selected according to its intended purpose, and an assessment should be made to ensure that AV is the most effective way to present the information. The decision to use a static or dynamic presentation of learning material, should be based on pedagogical grounds, for example, what would best support learners in mastering the study material. Animation should only be incorporated into learning activities when the characteristics of animation are consistent with the learning task, for example in some situations multiple

Guideline	Reason/explanation	Considerations/Comments
		discrete diagrams may serve the purpose better than animations, since this can allow comparisons and repeated inspection of details.
3. Animations for teaching purposes should be of small scope.		
4. Animations should not be too complex.		
5. Use a general-purpose framework, such as a standard GUI to manipulate the tool, for instance similar to a Windows environment with which the user is already familiar.	A general-purpose system that offers a common interface to a multitude of animations will make integration into a course easier.	Choose the system's platform to allow the widest possible target audience.
6. Students should be properly guided in how to use the PAV tool. This can be done by including a brief textual introduction and providing resources that help learners interpret the graphical representation that maps the visualization to the underlying algorithm by explaining it with text or narration, or reinforcing the relationship with instructional time during the course.		The situations where the visualization will be used also influence its design. Visualizations intended for self-study need much more explanatory cues than one that will be used in a classroom situation.
7. Use a conversational tone (using 'I' and 'you') in verbal or textual explanations.	According to the personalisation principle in the cognitive theory of multimedia learning, learners learn better from animation and narration when the narration is in conversational tone (using 'I' and 'you') since they are more involved and then work harder to understand the explanation.	
8. Include explanations in natural language synchronised with program state information. A text window, which is ideally always visible, audio track or hypertext explanation as well as pseudocode can be used for this purpose.		The spatial contiguity principle in the cognitive theory of multimedia learning asserts that on-screen text should be presented near to the part of the animation that it describes, to prevent wasting cognitive capacity in searching for the corresponding animation section.
9. Use the contiguity principle. The contiguity principle is based on cognitive load theory, and states that verbal explanations in animations should be presented contiguously in time and textual explanation in the same space as the illustrative material, so that the explanation and the pictorial information are active in working memory	Employing the contiguity principle should exclude the split-attention effect. The split-attention effect occurs when one source of information must be held in working memory while searching for another, because the two sources of information have to been integrated before it can be understood.	Research regarding learners' spatial ability should be taken into account when the contiguity principle is applied, since this principle is affected by learners' spatial ability. Spatial ability refers to the capacity to perceptually conceive the change in configuration that would result when objects are manipulated. Concurrent presentation of verbal and visual information benefits

Guideline	Reason/explanation	Considerations/Comments
simultaneously. This corresponds with the spatial contiguity principle in the cognitive theory of multimedia learning, which asserts that on-screen text should be presented near the part of the animation that it describes, to prevent wasting cognitive capacity in searching for the corresponding animation section.		mainly learners with a high spatial ability, since they have a better ability to build mental connections between the verbal and visual representations. Program code represents an abstract space that has to be navigated with the same cognitive strategies as used in natural environments. A strong positive correlation between students' spatial ability and their results in programming modules, with much lower correlations between their spatial ability and non-programming modules has been found. This seems to suggest that students with lower spatial ability struggle more with programming subjects. Students with a low spatial ability also use less effective navigational strategies when attempting to comprehend code. Therefore, it seems as if using verbal explanations in animation, even if the contiguity principle is applied, might be to the disadvantage of weak programming students.
10. Apply the modality principle. Modality refers to the sensory mode in which verbal information is presented: written or spoken. In cognitive load theory the modality principle suggests that textual explanations in animations should be presented in spoken format, as this allows more information to be processed visually.	The modality principle is intended to decrease the extraneous cognitive load. Dual coding, where visual and auditory presentations are used together, may enhance comprehension. The cognitive theory of multimedia postulates that integration is most likely to occur when the corresponding pictorial and verbal representations are in working memory at the same time. Accordingly, meaningful learning will be encouraged under instructional conditions that present pictorial and verbal information simultaneously. According to the temporal contiguity principle in the cognitive theory of multimedia, learners make better connections when corresponding narration and animation are presented simultaneously. The modality principle in the cognitive theory of multimedia maintains that learners learn better from animation and narration, than from animation and on-screen text, since the visual channel is less likely to be overloaded. That should provide more opportunity to build connections between corresponding words and	If dual coding is used, the animation and the narration should occur simultaneously. Although the modality principle is intended to decrease the extraneous cognitive load, this may have a negative effect if the speaker has a foreign accent, since the additional effort to decipher the accent adds to the cognitive load. Also, when learners have control over the pacing of the animation, written explanatory text is more effective than spoken explanatory text, since this allows the student more time to study the information. It is also much easier to move forwards and backwards through written text than through spoken texts, because the linearity of the spoken text makes it more difficult to follow when scanning through.

Guideline	Reason/explanation	Considerations/Comments
	pictures. The multimedia principle in the cognitive theory of multimedia, states that students learn better from both narration and animation than from narration alone, when the learner has to create the mental picture him- or herself. The redundancy principle in the cognitive theory of multimedia asserts that learners learn better from animation and narration, than from animation, narration and on-screen text. It is based on the same rationale as the modality principle.	
11. Avoid using extraneous material (words, sounds, video, and pictures).	The coherence principle in the cognitive theory of multimedia learning states that extraneous material (words, sounds, video, and pictures) should be excluded to prevent wasting cognitive resources on irrelevant material.	
12. Support flexible execution control with direct-manipulation animation (DMA) where learners interact directly with the navigation controls (such as buttons and sliders) of an animation to determine the direction of their viewing themselves. They should be able to move both forward and backward at their own speed as well as to rerun and execute the visualization in smooth motion. A structural view of algorithm's main parts may be included to allow the student to jump directly to a specific key point in the animation without a search or having to cover steps that they understand. In smooth motion the animation should be well-paced.	Flexible execution may create a flexible interface for the learner: When the algorithm animation is presented in discrete segments supplemented with explanations of the actions, students may then pause according to their needs. If they can also provide their own data or select between different sets of data, together this provides a flexible interface. Learners need sufficient time and mental resources to process and understand the relationships between various components in the animation. DMA supports this by allowing them to control their viewing sequence in such a way that they can visualize how a change in one parameter affects other parameters in the dynamic system. The *apprehension* principle states that "the structure and content of the external presentation should be readily and accurately perceived and comprehended." This means that the animation must be slow and clear enough to allow learners to perceive changes and to understand the changes in the relations between the different parts and the sequence of events. Pacing allows learners to control the tempo of	When learners have control over the pacing of the animation, written explanatory text is more effective than spoken explanatory text, since this allows the student more time to study the information. It is also much easier to move forwards and backwards through written text than through spoken texts, because the linearity of the spoken text makes it more difficult to follow when scanning through.

Guideline	Reason/explanation	Considerations/Comments
	presentation according to their own cognitive needs and therefore decreases the extraneous cognitive load, for example to reduce activities that impede learning. Execution in smooth motion can help users detect changes.	
13. Divide the display area into functional areas that are consistently used for the different types of information.	This prevents the display area from being cluttered.	Important information should be placed near the top left, since eye-motion studies show that the human gaze goes to the upper-left of a rectangular display and then moves clockwise.
14. Window management should allow all windows to be visible when the AV starts and might allow users to resize or reposition windows to suit the user.		
15. Care should be taken in deciding what information should be presented and how it should be done. An appropriate set of conventions in the form of the shape, size, colour, texture, sound and arrangement of objects to represent different information, should be developed and applied consistently.	A user-centred design is important. Consistent locations for buttons, sliders and switches will minimise perceptual and cognitive demands on learners. Providing alternative interaction methods such as sliders, or arrows on the screen to advance or backtrack, or keyboard arrows, can accommodate different navigation styles or learning preferences.	
16. Apply the *congruence* principle which states that "the structure and content of the external representation should correspond to the desired structure and content of the internal representation". The animation should therefore present the process or procedure in the same way and order that people visualize it.		
17. Use signalling, or cueing to draw the user's attention to critical areas of the visualization, for instance by using different colours, highlighting algorithmic actions, underlining words or using arrows to focus attention on a specific part of the animation.	Signalling assists meaningful learning, because it guides attention to relevant information and facilitates the efficiency of a visual search for the necessary information, thereby assisting the learner in selecting and organising the instructional material.	Although people do not learn more from colour displays than from black and white displays, colour helps people to remember and is more enjoyable to work with. A maximum of five colours, and preferably four only for novices, should be used to allow more short-term memory for information processing. Foveal (centre) and peripheral colours should be used appropriately. For example, blue is suitable for large backgrounds, while red and green should be used in the centre of the visual field. Strong contrasts of colours on the opposite of the colour wheel should be avoided

Guideline	Reason/explanation	Considerations/Comments
		since this produces vibrations, illusions of shadows and afterimages. Use familiar colour coding such as red for stop or danger. The same colour should be used consistently for related elements to assist conceptual comprehension without verbal clues. Use bright colours to draw attention. Colour can save screen space by for example using a small area changing in colour to indicate progress, rather than a bar or line. Non-speech sound can be used to draw the user's attention to an event. Since this may easily be an irritating feature, a flexible easily accessible user-configuration component should be included to allow users to specify the sound for each event and switching it on or off. Documentation, online training and examples should be given to prepare users for using this feature. The number of sounds should be restricted, as there is a threshold for the number of sounds that can be learned and remembered.
18. Include pseudocode for the algorithm.	Clear pseudocode should be provided to help the user relate state changes directly to algorithm's progress.	Providing the right set of features could reduce learning time, while using more features may result in increase in learning time with little pedagogical benefit. More time spent with AV does not necessarily translate into more learning.
19. Pseudocode lines should be highlighted synchronously as the animation executes.	This acts as a form of signalling or cueing, and may help the user relate state changes directly to algorithm's progress.	
20. Provide different views of the data, program or algorithm. This could include for example windows for both pseudocode and program animation, and both the logical and the physical view of a data structure as well as the distinction and connection between these views.	Prompts to explore different views and different data sets encourage student interaction and demonstrate algorithm behaviour in more detail. Multiple and multimodal representations, for example three distinct views of the animation may be used to demonstrate the algorithm behaviour – the analogy, a micro view with a small data set, and a macro view with a large data set.	Multiple views of the same algorithm should be used judiciously to prevent information overload.
21. Include capabilities for comparative algorithm analysis such as performance information that shows the algorithm's efficiency, or simultaneous	Prompts to explore the different algorithms or data sets may encourage user interaction.	

Guideline	Reason/explanation	Considerations/Comments
identical views of different algorithms manipulating the same data.		
22. Include the execution history so that learners can see previous steps.		
23. Adapt to the knowledge level of the user (the learner), for instance use a less complicated system for novices and base appropriate feedback on the assumed background knowledge of users, which should be made clear.	No AV can cater for all possible users. Animations intended for novices may have no benefits for students with prior knowledge. An analysis of the users, their needs, their tasks, the scope of the package and the resources available to developers is important. Novices need much more guidance in mapping the visualization to the program, as well as help in how to use the AV system, than experienced users. Short quizzes may help novices understand the material, while experienced users may want to integrate their own programs into the system.	The effectiveness of a presentation format depends on the degree to which it matches the learners' cognitive and comprehension processes. The effectiveness of guidelines to manage cognitive load in animation depends on several mediating factors, notably learners' prior knowledge, spatial ability, motivation and the age of learner. Learners with high spatial ability benefit more from animations with verbal explanations than learners with low spatial ability. The pattern of cognitive load may be affected by motivation and self-efficacy. Also, the efficiency of working memory deteriorates with age. Design guidelines might also interact, for instance when pacing is used, modality should be adapted since learner pacing seems to cancel the advantage of verbal over written explanations. On the other hand, combinations of guidelines, such as signalling and modality, might be particularly effective.
24. Scaffold learning with an animated analogy (for example illustrating merge-sort by sorting a deck of cards); pre-training; a sequence of simple-to-complex whole tasks, or segmentation. Simple-to-complex whole tasks allow learners to construct and automate schemas with low element interactivity and then gradually increase the complexity. Segmentation divides animations into several segments in which each segment presents an important part of a procedure or process.	Scaffolding decreases intrinsic cognitive load by reducing or managing the interactivity of the learning material. Segmentation decreases the extraneous cognitive load, it for instance reduces activities that impede learning.	
25. Perform user testing on each animation before using it for instruction to ensure ease of use.	A pedagogically useful AV should have no usability and reliability concerns.	
26. The AV should be integrated with a database for course management reasons to allow tracking students' responses.		

5.4 Design and development of a tutorial to teach tracing

This section describes the design and development of the tutorial to teach tracing to novices in the introductory programming module at Unisa, COS1511. The tutorial itself is described in section 5.4.1 and its design decisions are justified in section 5.4.2. The development process and the initial testing are discussed in section 5.4.3. Lessons learnt during the initial testing of the tutorial and its development are presented and related to the framework of guidelines for visualization in section 5.4.4.

5.4.1 The Drawing Variable Diagrams Tutorial[12]

The objective with developing the Drawing Variable Diagrams Tutorial was to enable the students to improve their skill at tracing computer programs, with the aim of developing their programming ability and ultimately increasing the pass rate for COS1511.

5.4.1.1 Tutorial specifications

The tutorial was developed in Adobe Flash Player 10 ActiveX. The screen dimensions fit a standard screen of 1 024 by 768 pixels. The tutorial consists of 21 activities. Each activity demonstrates the tracing of a program or program segment by drawing variable diagrams, statement by statement. Each program or program segment presents a specific programming concept, for example reserving memory space for variables, or a programming construct such as a `for` loop. Initially the activities ranged in length from seven to 60 steps, although some of the larger activities have been shortened to fewer steps in subsequent versions of the tutorial.

The introductory frame provides a menu that allows users to choose an activity, to view the instruction manual or to exit from the tutorial. In the initial version, a series of screenshots was used to demonstrate how to use the tutorial. This was replaced with a complete instruction manual in PowerPoint format in subsequent versions (see Appendix E for both sets of instructions).

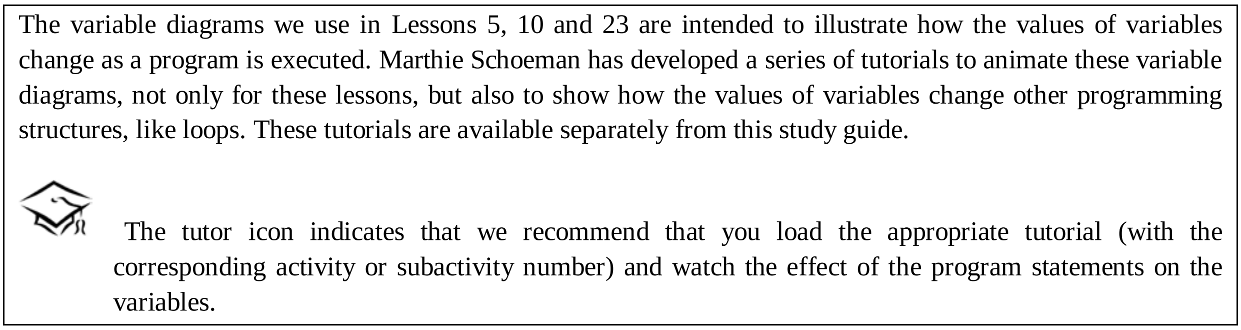
5.4.1.2 Activities and implementation of activities

As mentioned in section 5.4.1.1, the Drawing Variable Diagrams Tutorial consists of 21 activities from the Study Guide for COS1511. The Study Guide contains 30 lessons, and each lesson contains a number of activities students are supposed to do while working through the Study Guide. Not all activities in the Study Guide are included in the tutorial, since not all of them require drawing variable diagrams. Also, not all activities in the Study Guide that do require drawing variable diagrams are included in the tutorial. As mentioned in the previous paragraph, each of the activities included, was chosen either to introduce a specific concept such as reserving memory space with a declaration

[12] A large part of this section was published in Schoeman, Gelderblom and Smith (2012).

statement, or to show how to trace a program construct such as a `for` loop. To scaffold learning, an example of how to trace each new programming construct taught in the Study Guide is included as an activity in the tutorial. Note that in the Study Guide, some of the scaffolding activities do not require students to draw variable diagrams. Examples of these are Activity 4.b that shows how assignment statements change the values in variable diagrams; Activity 8.a.iii that demonstrates how to draw variable diagrams for a simple `if else` statement; and Activity 9.a.v that demonstrates how to trace a `while` loop with variable diagrams. Consequently the activity numbers in the Drawing Variable Diagram Tutorial are not numbered as would be expected. Table 5.2 shows the activity number in the tutorial and the concept or construct introduced in that activity. The activity number in the tutorial corresponds to that in the Study Guide.

The tutor icon as illustrated in Figure 5.Figure 5.2 is used to indicate that students should load the tutorial and watch the corresponding activity.



The variable diagrams we use in Lessons 5, 10 and 23 are intended to illustrate how the values of variables change as a program is executed. Marthie Schoeman has developed a series of tutorials to animate these variable diagrams, not only for these lessons, but also to show how the values of variables change other programming structures, like loops. These tutorials are available separately from this study guide.

The tutor icon indicates that we recommend that you load the appropriate tutorial (with the corresponding activity or subactivity number) and watch the effect of the program statements on the variables.

Figure 5.2 The tutor icon as used in the COS1511 Study Guide

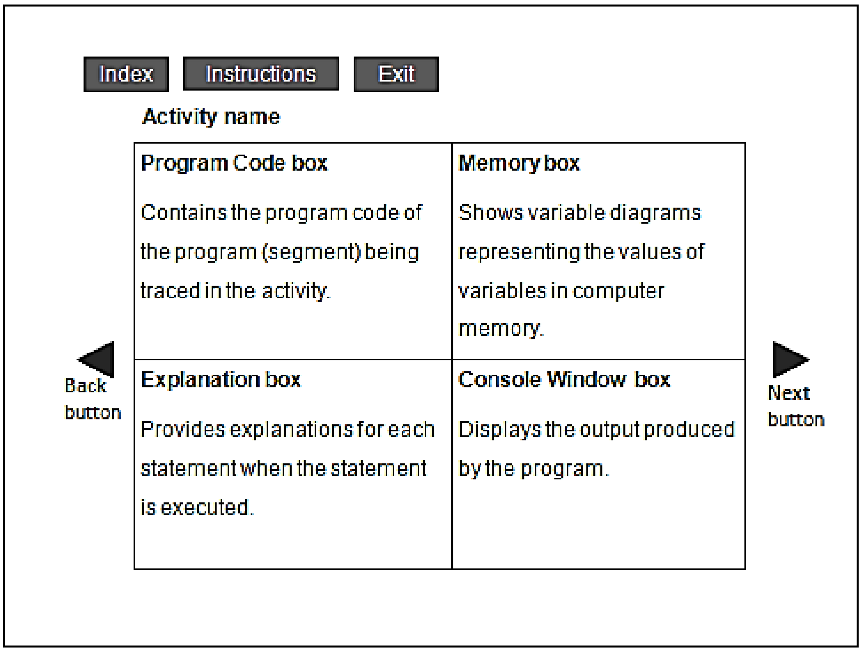
Screen layout and boxes

As the program is traced, each statement is explained. To explain a statement, the screen is divided into four panels, as shown in the diagrammatic representation of the layout in Figure 5.3, namely one each to show the program code, the computer memory, the program output and an explanation of the statement. The purpose of each panel is briefly explained inside the corresponding box in the diagrammatic representation (Figure 5.3).

Figure 5.4 displays a screenshot of Activity 5.a in the Drawing Variable Diagrams Tutorial. A typical run is described in the next section, using a statement in Activity 5.a as example to show what happens when a statement is ‘executed’.

Table 5.2 List of activities in the drawing variable diagrams tutorial

Activity number in Drawing Variable Diagrams Tutorial	Concept or construct animated in Drawing Variable Diagrams Tutorial
3.a.i	Shows how a declaration statement such as `int a;` reserves memory space.
4.a.ii	Demonstrates tracing and using variable diagrams for the assignment statement.
4.b	Demonstrates and trace a program line by line and use variable diagrams to show tracing of declaration statements and how the values of variables change with assignment statements.
5.a	Demonstrates line by line tracing of a program to illustrate arithmetic operators.
8.a.iii	Demonstrate tracing a simple `if else` statement.
9.a.v	Demonstrates tracing a `while` loop that prints values from 10 to 20.
12.a.i	Demonstrates tracing nested `if` statements.
12.b.i	Demonstrates the effect of braces (i.e. '{' and '}') on nested `if` statements.
13.a.i	Demonstrates tracing `switch` statements.
14.d	Demonstrates tracing a `while` loop for which the number of iterations cannot be determined beforehand.
14.h.ii	Demonstrates tracing a `while` and a `do`...`while` loop that both determine the biggest of a number of positive integers, to illustrate the difference between `while` and `do`...`while` loops.
15.b.iii	Demonstrates tracing a `for` loop.
16.a.ii	Demonstrates tracing two nested `for` loops.
18.a.ii	Demonstrates tracing a value-returning user-defined function with one value parameter.
21.a.vi	Demonstrates tracing functions with value and reference parameters.
22.a.vi	Demonstrates tracing a `void` function with a reference parameter.
23.a	Use variable diagrams to illustrate the difference between value and reference parameters and integrate the concepts covered in activities 18.a.ii, 21.a.vi and 22.a.vi.
24.a.iii	Demonstrates tracing a one-dimensional array.
26.a.iii	Demonstrates tracing a two-dimensional array.
27.a	Demonstrates tracing strings.
28.a.i & 28.a.ii combined	Demonstrates tracing a struct.



Index Instructions Exit

Activity name

Program Code box

Contains the program code of the program (segment) being traced in the activity.

Memory box

Shows variable diagrams representing the values of variables in computer memory.

Explanation box

Provides explanations for each statement when the statement is executed.

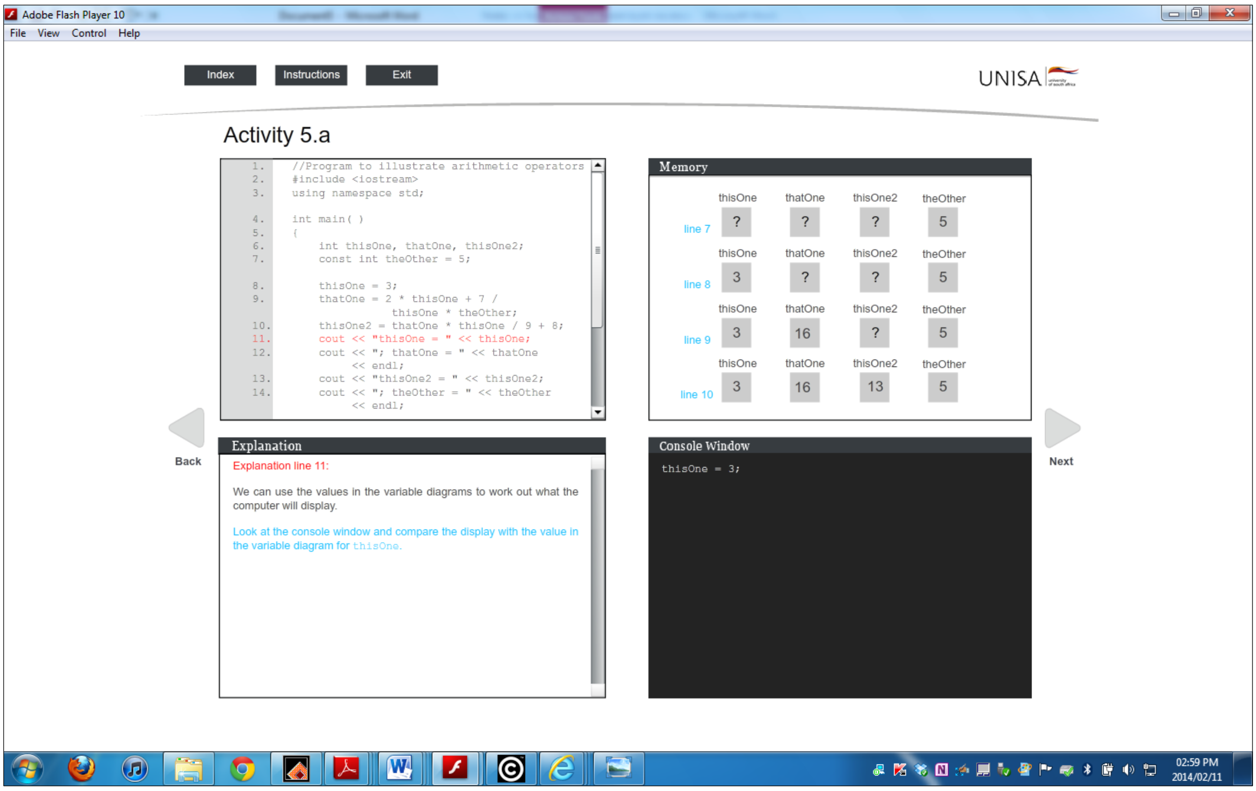
Console Window box

Displays the output produced by the program.

Back button

Next button

Figure 5.3 Diagrammatic representation of screen layout for tutorial, presenting the purpose of each panel. The menu appears on top, and the navigation buttons (Back and Next), to the left and right of the panels.



Activity 5.a

```
 1.  //Program to illustrate arithmetic operators
 2.  #include <iostream>
 3.  using namespace std;

 4.  int main( )
 5.  {
 6.      int thisOne, thatOne, thisOne2;
 7.      const int theOther = 5;

 8.      thisOne = 3;
 9.      thatOne = 2 * thisOne + 7 /
                    thisOne * theOther;
10.      thisOne2 = thatOne * thisOne / 9 + 8;
11.      cout << "thisOne = " << thisOne;
12.      cout << "; thatOne = " << thatOne
              << endl;
13.      cout << "thisOne2 = " << thisOne2;
14.      cout << "; theOther = " << theOther
              << endl;
```

Memory

	thisOne	thatOne	thisOne2	theOther
line 7	?	?	?	5
line 8	3	?	?	5
line 9	3	16	?	5
line 10	3	16	13	5

Explanation

Explanation line 11:

We can use the values in the variable diagrams to work out what the computer will display.

Look at the console window and compare the display with the value in the variable diagram for thisOne.

Console Window

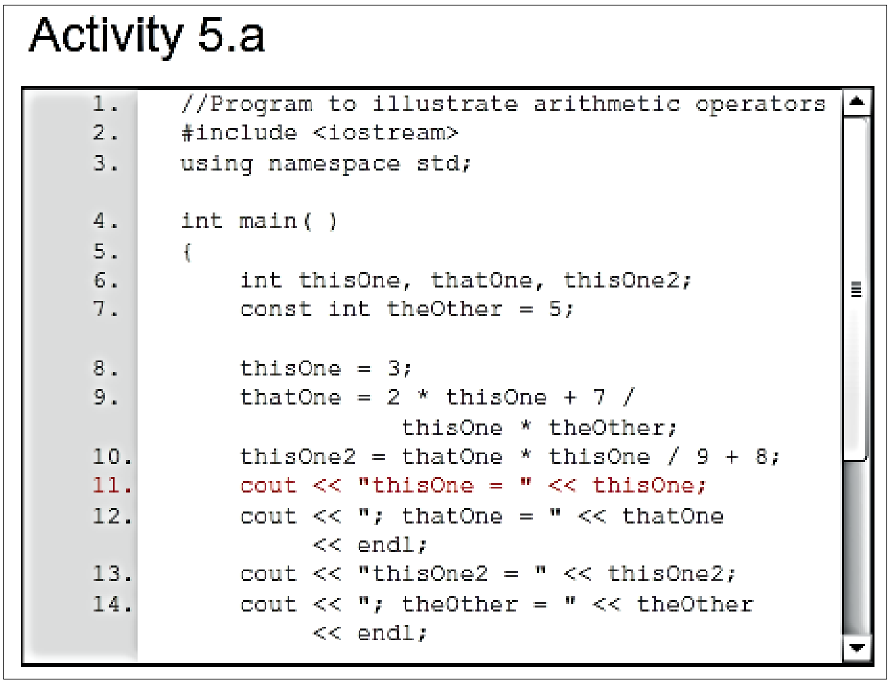
```
thisOne = 3;
```

Figure 5.4 A screenshot of activity 5.a in the Drawing Variable Diagrams Tutorial

A typical run

In the Program Code box (see Figure 5.5) the program (segment) being traced, is displayed. The statements are numbered to facilitate explanation and the drawing of variable diagrams. When a statement is ‘executed’, it is highlighted in red in the Program Code box and explained in the Explanation box while the variable diagrams depicting the state of the computer memory at that specific time are reflected in the Memory box and the state of the Console window portrays the output at that stage. Figures 5.8 to 5.11 respectively show a representation of the view in each of the four panels for the same statement.

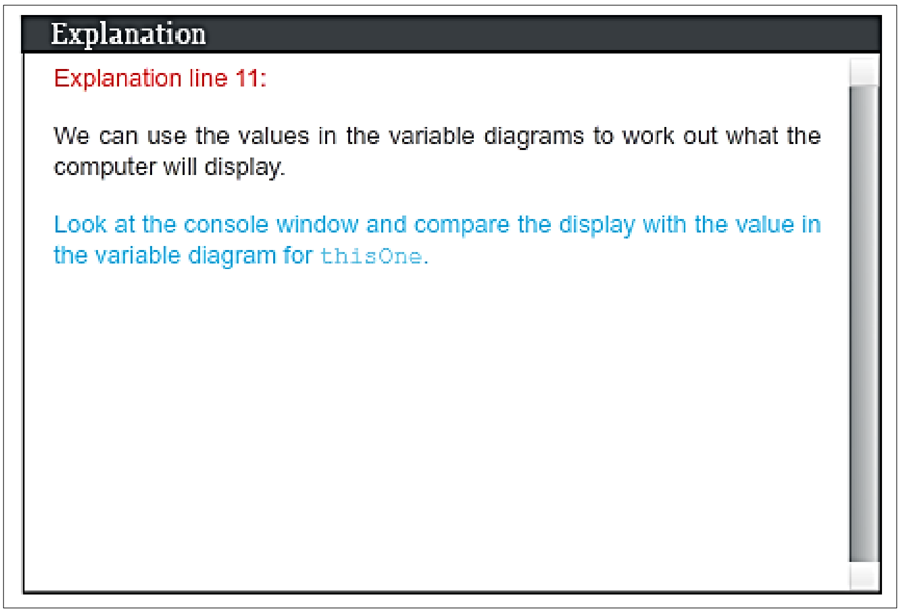
For example, when the statement in line 11 in the Program Code box in Figure 5.5 is ‘executed’, the Explanation box in Figure 5.6 is also numbered ‘Explanation line 11’, and gives an explanation of what happens when this statement is executed. Since the statement is an output statement, the Explanation box prompts the user to look at the output produced by this statement in the Console Window box in Figure 5.7. In the Memory box in Figure 5.8, the variable diagrams show the contents of the computer memory at this stage. The Memory box displays variable diagrams for lines 7 to 10 to show the values of the variables as they are modified in each statement. The question marks in the variable diagrams indicate variables that have not yet been initialised. The user can now confirm that the value the variable `thisOne` has in memory, is in fact displayed in the output.



Activity 5.a

```
 1.   //Program to illustrate arithmetic operators
 2.   #include <iostream>
 3.   using namespace std;

 4.   int main( )
 5.   {
 6.       int thisOne, thatOne, thisOne2;
 7.       const int theOther = 5;

 8.       thisOne = 3;
 9.       thatOne = 2 * thisOne + 7 /
                    thisOne * theOther;
10.       thisOne2 = thatOne * thisOne / 9 + 8;
11.       cout << "thisOne = " << thisOne;
12.       cout << "; thatOne = " << thatOne
               << endl;
13.       cout << "thisOne2 = " << thisOne2;
14.       cout << "; theOther = " << theOther
               << endl;
```

Figure 5.5 The Program Code box. Line 11 is highlighted because this statement is executed. A scroll bar appears to right because all the program code does not fit into the panel.

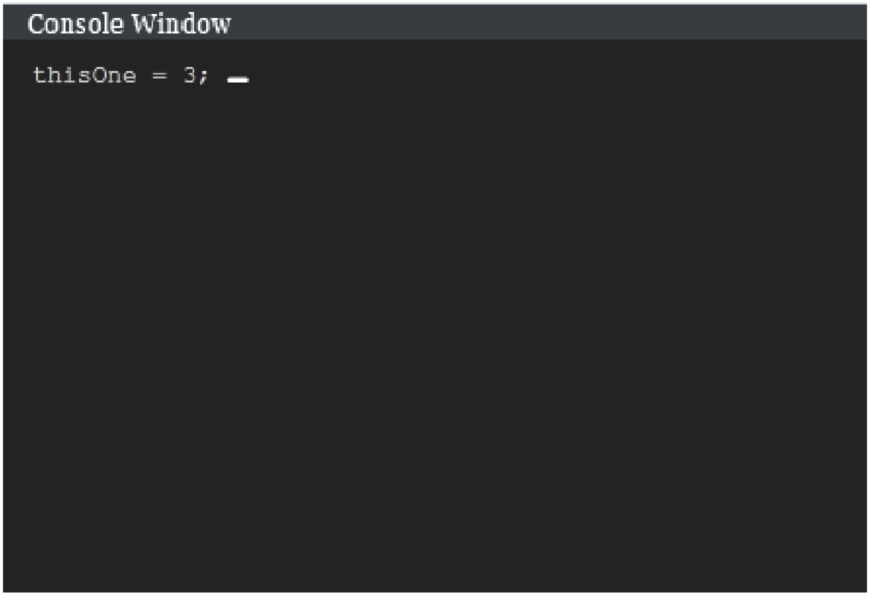


Explanation line 11:

We can use the values in the variable diagrams to work out what the computer will display.

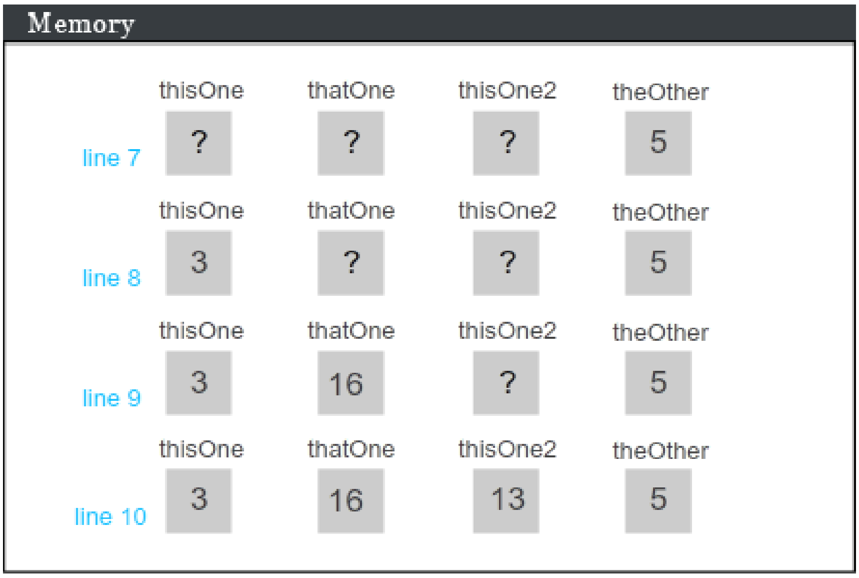
Look at the console window and compare the display with the value in the variable diagram for `thisOne`.

Figure 5.6 The Explanation box. The prompt to look at the output is displayed in blue.



```
thisOne = 3; _
```

Figure 5.7 The Console Window box. In the tutorial the console window is black, with white text. The '–' next to the output, flickers, as it does in the IDE.



	thisOne	thatOne	thisOne2	theOther
line 7	?	?	?	5
line 8	3	?	?	5
line 9	3	16	?	5
line 10	3	16	13	5

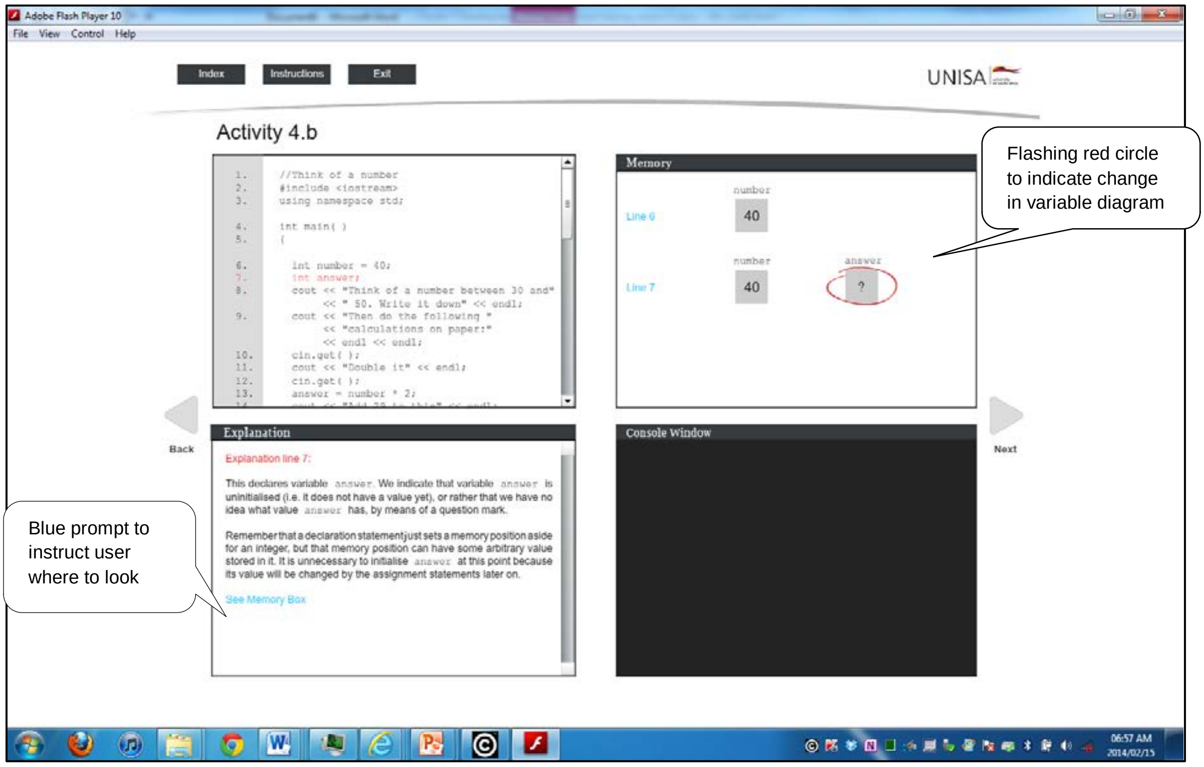
Figure 5.8 The Memory box. The line numbers'line 7' to 'line 10' are displayed in blue. If a variable's value is changed in the statement, the variable diagram box will be circled in red.

Cueing

Cueing is used to guide learners' attention to changes in the memory box and the Console window. This is a key element to ensure that learning takes place. Cues are given with blue prompts in the Explanation box to instruct them where to look, or red circles in the Memory box to indicate changes in the variable diagrams (see Figure 5.9).

The user is prompted to look at the Console Window box when output is displayed as well as when input is accepted by the program. The tutorial does not allow the user to input his or her own values, but instead either assumes that specific values will be input and displays these values then in the Console Window box. Alternatively, it lets the user choose between two or three values, in which case the chosen value is displayed in the Console Window box as if the user has keyed it in.

The Explanation box also prompts the user when to look at the Memory box. When a statement in the Program Code box, changes the value of a variable, the Explanation box displays a prompt to look at the Memory box and the corresponding variable diagram in the Memory box is circled in red to draw attention. Sometimes the user is prompted to look at both the Console Window box and the Memory box, see for instance Figure 5.6. Another scenario where the user is prompted to look at both the Memory box and the Console window occurs when an input statement is 'executed' and an input value for a variable is 'read' from the Console Window and stored in memory. When this happens, the new value for the variable is changed in its variable diagram in the Memory box.



Activity 4.b

```
1.   //Think of a number
2.   #include <iostream>
3.   using namespace std;

4.   int main( )
5.   {

6.     int number = 40;
7.     int answer;
8.     cout << "Think of a number between 30 and"
            << " 50. Write it down" << endl;
9.     cout << "Then do the following "
            << "calculations on paper:"
            << endl << endl;
10.    cin.get( );
11.    cout << "Double it" << endl;
12.    cin.get( );
13.    answer = number * 2;
```

Explanation

Explanation line 7:

This declares variable answer. We indicate that variable answer is uninitialised (i.e. it does not have a value yet), or rather that we have no idea what value answer has, by means of a question mark.

Remember that a declaration statement just sets a memory position aside for an integer, but that memory position can have some arbitrary value stored in it. It is unnecessary to initialise answer at this point because its value will be changed by the assignment statements later on.

See Memory Box

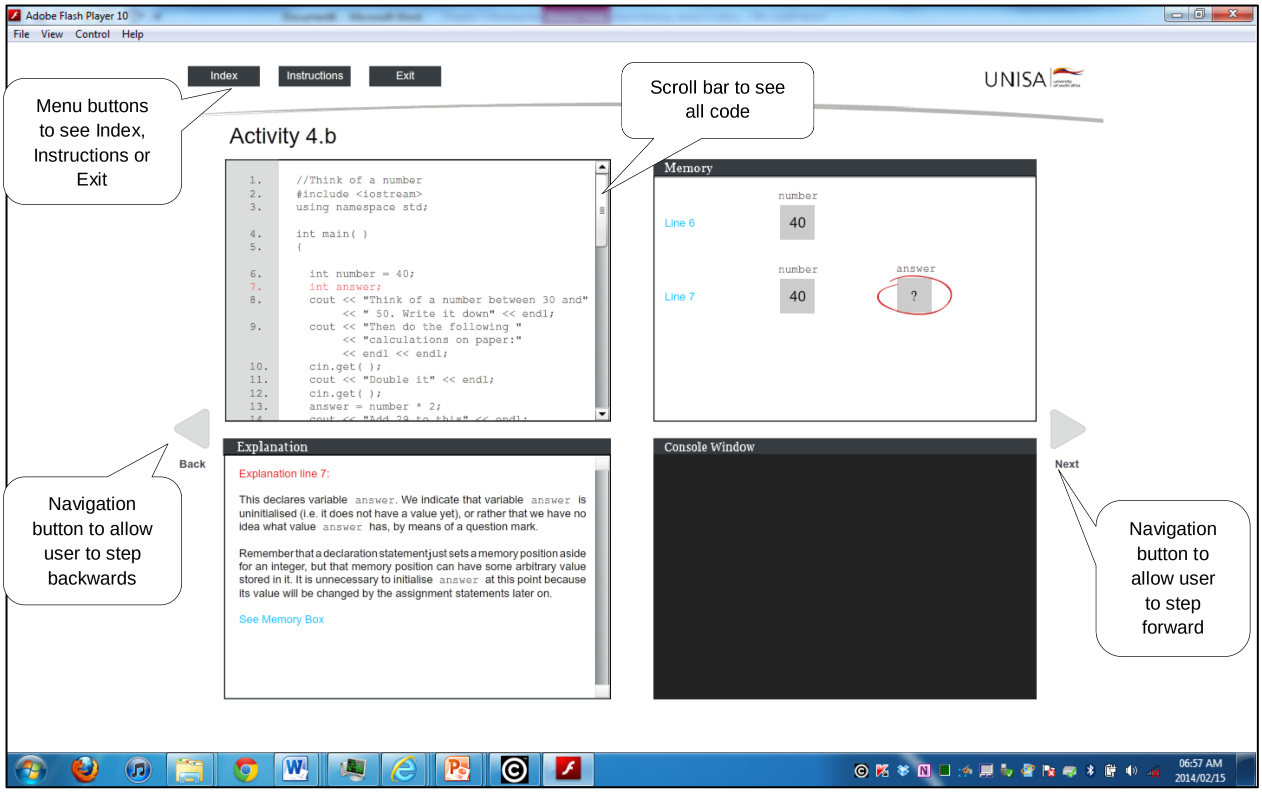
Flashing red circle to indicate change in variable diagram

Blue prompt to instruct user where to look

Figure 5.9 Cueing

Navigation

As shown in Figure 5.10, each panel will display a scroll bar to allow the user to see all the code, diagrams, output or text if it does not fit into the panel. Apart from the four panels, the screen also incorporates navigation buttons to allow users to step forward and backward at their own pace through the program trace, and to exit the tutorial or return to the index. Occasionally the tutorial allows the user to choose between two options during an activity, see for example Activity 8.a.iii, and then proceed according to this choice.


Adobe Flash Player 10
File View Control Help
Index
Instructions
Exit
UNISA
Menu buttons to see Index, Instructions or Exit
Scroll bar to see all code
Activity 4.b
Memory
Line 6
number
40
Line 7
number
40
answer
?
Console Window
Back
Next
Navigation button to allow user to step backwards
Navigation button to allow user to step forward
06:57 AM
2014/02/15

```
1.   //Think of a number
2.   #include <iostream>
3.   using namespace std;

4.   int main( )
5.   {

6.     int number = 40;
7.     int answer;
8.     cout << "Think of a number between 30 and"
            << " 50. Write it down" << endl;
9.     cout << "Then do the following "
            << "calculations on paper:"
            << endl << endl;
10.    cin.get( );
11.    cout << "Double it" << endl;
12.    cin.get( );
13.    answer = number * 2;
14.    cout << "Add 29 to this" << endl;
```

Explanation

Explanation line 7:

This declares variable `answer`. We indicate that variable `answer` is uninitialised (i.e. it does not have a value yet), or rather that we have no idea what value `answer` has, by means of a question mark.

Remember that a declaration statement just sets a memory position aside for an integer, but that memory position can have some arbitrary value stored in it. It is unnecessary to initialise `answer` at this point because its value will be changed by the assignment statements later on.

See Memory Box

Figure 5.10 Navigation

5.4.2 Motivation for design decisions

The typical purpose of program visualizations is to show the contents of the internal computer memory during program execution. In contrast, as discussed in section 3.2, the objective of this tutorial is to teach students how to draw variable diagrams so that they can trace programs manually. The design of the tutorial is therefore aimed at assisting the students to develop a mental model of how to keep track of what happens in computer memory by drawing variable diagrams. Design decisions were based both on the context in which the tutorial will be used as wel as the guidelines form the framework developed in section 5.3. Design decisions based on the context are discussed in section 5.4.1, while decisions based on the guidelines are explained in section 5.4.2.

5.4.2.1 Design decisions based on the context

Factors in the context that played a role in design decisions for the tutorial include the high cost of bandwidth in South-Africa, large student numbers (from approximately 1 600 up to 3 000 per semester), the time constraints of the semester system, inadequate Internet access and the technical proficiency level of first-year students in the Unisa environment (Ragan in Ury, 2005). The technical proficiency level of the students, in particular, may differ considerably due to the different pre-requisites for the wide variety of degrees to which COS1511 is offered (see Table 4.2 in section 4.3.4.1).

An important consideration was that including existing programming visualization tools in the course material would require students to learn another environment in addition to the prescribed IDE and compiler. In the semester system with limited time for lecturers to cover programming fundamentals in detail, and for students to develop problem-solving and logic skills, high-level tools such as the IDE and libraries may overwhelm the students more than it empower them (Leung, 2006). Therefore a customised PV tutorial based on the Study Guide for COS1511 was developed, since correspondence between the artifact and the related study material is such an important factor in its acceptance as a learning tool (Naps, Röβling et al., 2003; Röβling, 2010). The tutorial resembles the static diagrams provided in the Study Guide for COS1511 as closely as possible to enhance its comprehension. To further align the tutorial with the study material, the Console Window box representing output from the program, imitates that of the IDE used by the COS1511 students. The purpose of this is to assist students in developing and reinforcing their own mental models of what happens when a program is executed. The term 'console window' is also the term used in the IDE utilised by the students. To demonstrate the use of the tutorial, it is incorporated in the students' study material with compulsory assignments.

Since Unisa students tend to have limited or intermittent internet access and unreliable postal systems, the tutorial is supplied on CD as part of the study material in a format that allows users to install the tutorial from the CD. To deal with unreliable postal systems, it may also be downloaded from the course website.

5.4.2.2 Design decisions based on the framework of guidelines

Most of the guidelines from the framework presented in Table 5.1 have been used in the design and development of the tutorial to teach tracing, as is discussed below. Reasons and explanations for those that were not implemented and those where deviations from a guideline have been implemented, are offered.

Since users' level of engagement has been shown to play a major role in the success of a visualisation, learners are presented with activities at certain points in the presentation to engage them. As recommended in Guideline 1, they are actively engaged with self-assessment exercises in the form of tickler questions, and questions that prevent the user from continuing without a correct answer. Should a student answer a question that prevents the user from continuing incorrectly, an explanation with the correct answer is provided. The other forms of engagement were considered beyond the scope of the purpose of the tutorial.

To ensure acceptance the tutorial is integrated in the study material as discussed in section 5.4.1.2, following Guideline 2. The animations are small (Guideline 3) and not too complex (Guideline 4).

Because learners would be using the tutorial on their own, the interface to the tutorial is kept very simple with only three options, namely *Index* (to see the list of activities), *Instructions* (to learn how to use the tutorial) and *Exit* (to exit from the tutorial). When the mouse is positioned over an option, a drop-down explanation indicates the purpose of the option. Guideline 5 recommends using a general-purpose framework similar to an environment with which the user is already familiar with. The simple interface used for the tutorial therefore did not follow this guideline.

Since the learners would be using the tutorial at home, without assistance, for the first version of the tutorial, a series of screen shots was used as instructions to show the users how to use the tutorial (see Appendix E.1). However, during the qualitative investigation in first implementation cycle, it became clear that this was not sufficient. Accordingly the instructions on how to use the tutorial was adapted and changed to a to a Powerpoint presentation covering the following topics, including an example on how to use the tutorial as the last topic(see Appendix E.2):

1. Introduction
2. What is a variable?
3. What is a variable diagram?
4. The purpose of variable diagrams
5. The purpose of the Drawing Variable Diagrams Tutorial
6. Activities in the Drawing Variable Diagrams Tutorial
7. How to use the Drawing Variable Diagrams Tutorial
8. The Landing Page
9. The Index page
10. Explanation of an activity screen
11. The Program code box
12. The Memory box
13. The Explanation box
14. The Console window box
15. The relationship between the four boxes on the screen for an activity
16. How to follow how variable diagrams are drawn
17. Notes
18. At the end of an activity
19. Using the Drawing Variable Diagrams Tutorial to see how variable diagrams are drawn for activity 3.a.i

This corresponds to guideline 6 that recommends that students should be properly guided in how to use the PAV tool, especially when used in self-study.

A conversational tone (Guideline 7) is used in the natural language explanations which are synchronised with the program state information (Guideline 8) in the four panels displayed simultaneously to explain a statement.

To allow students to form a mental model of what happens in computer memory; as well as how to represent and keep track of it by drawing variable diagrams, the screen layout presents the program simultaneously at four levels. The four panels used in the screen layout are shown in Figure 5.3 (one each to show the program code, the computer memory, the program output and an explanation of the step). In this way a student can keep track of what happens when a statement is executed, see how to draw the variable diagrams indicating the change in memory (if any), read the explanation and also see what output (if any) the statement produces. This follows guideline 9, the contiguity principle, but only followed insofar as the textual explanations are presented in the same space as the illustrative material.

To engage students, the tutorial is interactive and allows direct user control in the form of navigation buttons to move forward or backward through an activity. This allows students to determine the pace at which, and the direction in which the visualization unfolds, following Guideline 12 (supporting flexible execution). As a result, guideline 10, the modality principle, that suggests textual explanations should be spoken, was not adhered to, since guideline 12 is particularly suitable to the ODL environment at Unisa. In the next paragraph the reasons for not following Guideline 10 are discussed in more detail.

Many of Unisa’s students come from a disadvantaged educational background. Unisa research shows that the average first-year student, from a background where reading was neglected, could have the reading ability of twelve-year olds, not eighteen-year olds (Kilfoil, 2008). Other sources confirm that South-African learners at both school and tertiary level, frequently perform below expectation in terms of reading (Gous & Roberts, 2014; Hefer, 2013; Nel, Dreyer & Klopper, 2004). The 2014 National Benchmark tests in academic Literacy for South-Africa too indicate that only approximately 33% of applicants to higher education for 2015 had the ability to cope with academic literacy demands of tertiary courses (Cliff, 2015). When text is combined with other visual material such as images or film, the eye has to move between the text and the rest of the visuals on the screen which places more demands on attention and adds to the cognitive load as information has to be combined from two channels (Hefer, 2013). Guideline 12, supporting flexible execution control with DMA so that learners can control the speed and direction of the animation to suit their learning style and comprehension ability, is therefore particularly suitable for the ODL environment at Unisa, as this will allow learners to process and understand the relationship between the various components in the animation at their own pace. Flexible execution control is also highly recommended in both CER and EP, as it provides a flexible interface that allow learners to pause and process material at their own pace (Chan & Black, 2005; Hansen et al., 2002) which corresponds with the apprehension principle (Tversky et al., 2002) and decreases the extraneous cognitive load (Wouters et al., 2008). With flexible execution control, written explanatory text is more effective than spoken explanatory text and easier to follow when moving forwards and backwards through the animation (Tabbers et al., 2004). Regardless of the accent of the speaker used in the animation, it would be foreign to some students, since many of them study in their second or third language, which would add to the cognitive load (Mayer et al., 2003).

Guideline 11 (avoid using extraneous material) was followed with caution, because the user has to be prompted judiciously, that is neither too much nor too little. For example, displaying variable names only above each column instead of above each line in the Memory box (see Figure 5.14), would offer too little information.

The four panels used to explain a statement follows Guideline 13, since they are used consistently for the same information. Guideline 14 was followed partly since all windows are visible during the entire animation, but users cannot resize them.

Complying with Guideline 15, a user-centred design with consistency in screen layout and navigation buttons is followed. The cues used to guide users' attention (Guideline 17) are always in the same format. All prompts guiding the user to look at either the Console Window box or the Memory box are displayed in blue, while the circles in the Memory box to draw attention to changes in the variable diagrams are always red. In this way, it becomes 'automatic' knowledge, just enough to nudge the user where to pay attention, without detracting from comprehension. A lean, elegant design with roll-overs displaying the purpose of a button further minimises the cognitive load.

Changes in variable diagrams in the Memory box are only effected when a program statement that causes a change in the internal memory is executed. Therefore, the Memory box will not display new variable diagrams for each program line. This shows the student that memory does not change without a program instruction, and it avoids distracting the student by an apparent change in the Memory box which is in effect only a change in line number, thereby reducing extraneous cognitive load.

When demonstrating variable diagrams for activities with loops, both the Explanation box and the Memory box indicate which iteration of the loop is executed. This helps the user to keep track of what happens in memory, and so assists in developing the user's mental model of what changes in memory during each step in the loop's execution.

The tutorial also follows Guideline 16, Tversky et al.'s (2002) congruence principle, to present the process in the same way that people visualize it, again with the purpose of reinforcing learners' mental model of program execution.

Pseudocode was not included as recommended by Guideline 18, since the programs that are visualized are very simple. However, in line with Guideline 19 that recommends highlighting pseudocode synchronously as the animation executes, the program lines are highlighted when they are executed.

The combination of variable diagrams, the program code, a console window to show input and output as well as an explanation, follows Guideline 20 that recommends providing different views of the data, program or algorithm, to an extent, though not necessarily exactly as intended by the guideline.

Guideline 21 (capabilities for comparative analysis) is followed in some cases for example in activity 8.a.iii, where students may choose between two values when an `if else` statement is executed; activity 12.b.i where the effect of braces on nested `if` statements are demonstrated; and activity 23.a where the same function is demonstrated with value, reference or a mix of value and reference parameters.

The execution history is shown by keeping the variable diagrams from previous statements visible in the Memory window, to allow users to keep track of what happens when a statement is executed. This corresponds to Guideline 22.

Since the tutorial is intended for novices with no or little background of programming, the explanations are aimed at them, following guideline 23 that indicates adapting to the knowledge level of the user. Accordingly, more experienced users may have no need for the tutorial, and apart from using it for revision for the examination or to refresh their memory, once they have mastered drawing variable diagrams for a specific construct, students would probably not use it again.

To scaffold learning as Guideline 24 indicates, each new programming construct is demonstrated when it is introduced in the Study Guide, although the Study Guide itself does not show how to draw variable diagrams for each construct (see section 5.4.1.2).

As per Guideline 25, the usability of the tutorial will be investigated in the Unisa's School of Computing's HCI laboratory, to determine how students use it and to adapt it where problems are identified in the third phase of this study (the two iterative cycles of testing and refinement of the Drawing Variables tutorial).

Guideline 26, incorporating the animation with a database for course management, has not been followed, since students receive it on a CD and use it without a network connection at home. They would probably not use an activity again once they have mastered drawing variable diagrams for the construct demonstrated in the specific activity, unless it is for revision purposes. Students with some programming background may also not need and use the tutorial at all. In the third phase of this study (the two iterative cycles of testing and refinement of the Drawing Variables tutorial), how students use the tutorial was investigated by means of a questionnaire on their computing background, use of and experience of using the tutorial.

5.4.3 Development process and initial testing[13]

The tutorial has been designed by the candidate and developed by a team of three students at the Open Window School of Visual Communication in Pretoria. The design is based on the way variable diagrams are presented in the study material, combined with the manner in which the IDE used by the students displays output.

For each activity, the designer provided the program code with numbered statements, and the explanations and output (if any) corresponding to each statement, in a Word file to the developers. The program code showed the required indentation. The designer also indicated where the different prompts should appear in the explanation text. She drew variable diagrams for each statement that caused a change in memory by hand, and indicated where the cues to draw attention to changes (red circles) should be shown. The developers then developed the activities in Adobe Flash Player 10 ActiveX.

Initial testing was done by executing each activity and checking statement by statement, whether the correct explanation, output and variable diagrams are displayed. Program indentation, prompts and cues were checked. The navigation buttons that allow the user to proceed backwards and forwards in the correct order, according to program execution, were also checked.

5.4.4 Lessons learnt

In this section lessons learnt during the development of the tutorial as well as during the initial testing are described, followed by a set of general guidelines for the design and development of visualizations to teach programming.

5.4.4.1 Lessons learnt during the development of the tutorial[14]

Initially the developers did not always work at the same venue at the same time, which led to small inconsistencies in the tutorial. This provided some valuable lessons, of which the first is that, if different programmers are working on different parts of a tutorial, they should work together at the same venue. It led, for example, to three different versions of cueing, as can be seen in Figure 5.11. This was not necessarily a bad thing, because it allowed a choice. The first option had a solid red line around the variable diagram; the second option had a flashing red background in the variable diagram box, with the value displayed in black and the variable diagram circled by a red circle; while the third option circle was circled in red, with the value of the variable displayed in red on a grey background.

[13] A large part of this section was published in Schoeman, Gelderblom and Smith (2012).

[14] A large part of this section was published in Schoeman, Gelderblom and Smith (2012).

This was adapted to the fourth option in which the value is circled in a flashing red. Eventually the fourth option was used to draw users' attention to changes in the Memory box.

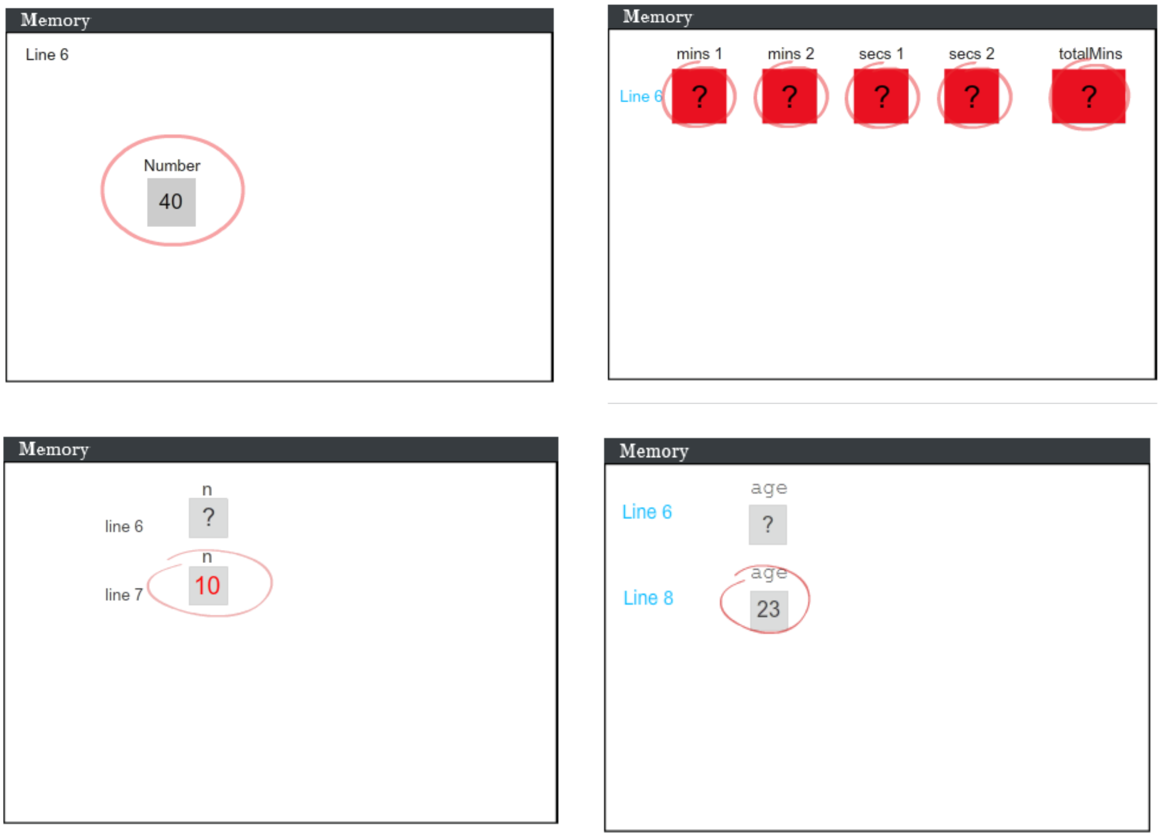
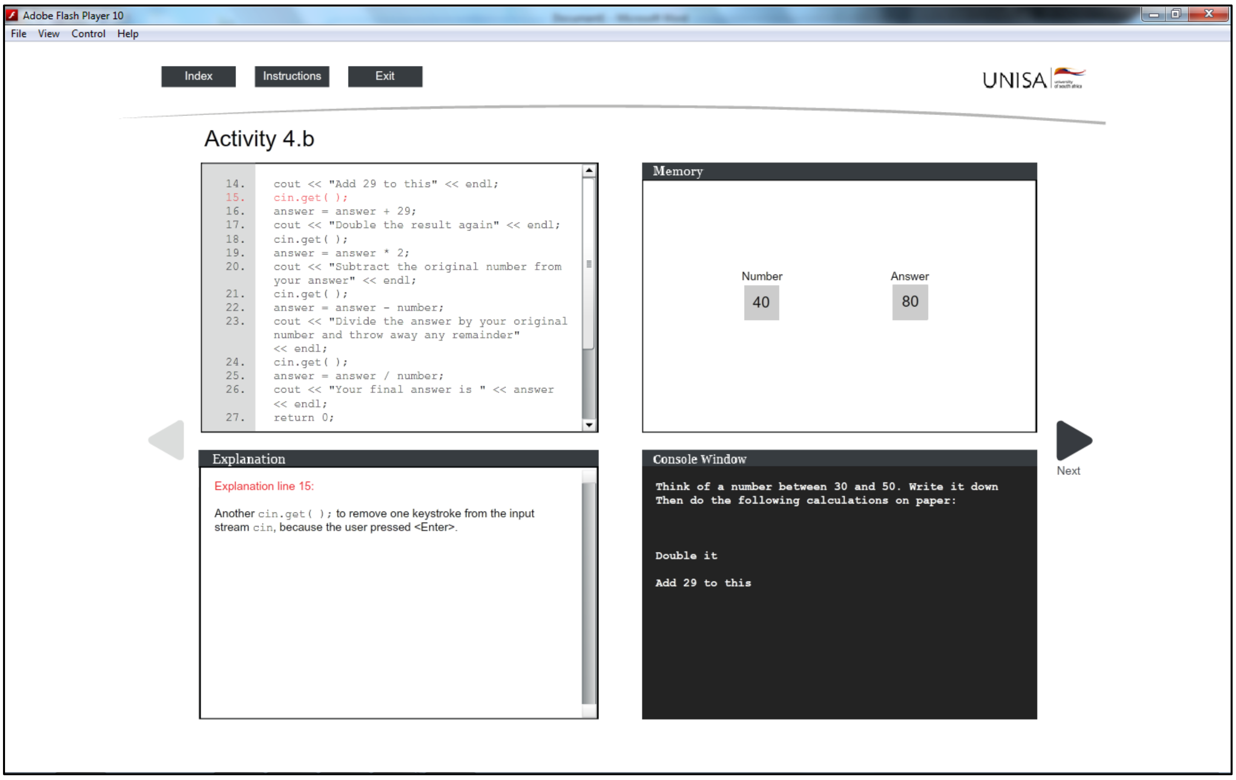


Figure 5.11 Four different versions of cueing to draw attention to changes in the memory box

One of the points debated by the team offering COS1511, related to whether variable diagrams for all the previous program lines executed should be shown, versus showing only variable diagrams for the current values in memory. Also as a result of the developers not always working together, both these options were implemented. Looking at the version where only the current values in memory are displayed, it became apparent that this was not advisable. For example, when only the current values of variables are shown, a statement such as

```
answer = answer + 29;
```

which changes the value of variable `answer`, as shown in Figure 5.13, causes the user to backtrack to the view shown in Figure 5.12 in order to verify what happened. Comparing this with Figure 5.6



Activity 4.b

```
14.  cout << "Add 29 to this" << endl;
15.  cin.get( );
16.  answer = answer + 29;
17.  cout << "Double the result again" << endl;
18.  cin.get( );
19.  answer = answer * 2;
20.  cout << "Subtract the original number from
     your answer" << endl;
21.  cin.get( );
22.  answer = answer - number;
23.  cout << "Divide the answer by your original
     number and throw away any remainder"
     << endl;
24.  cin.get( );
25.  answer = answer / number;
26.  cout << "Your final answer is " << answer
     << endl;
27.  return 0;
```

Memory

Number	Answer
40	80

Explanation

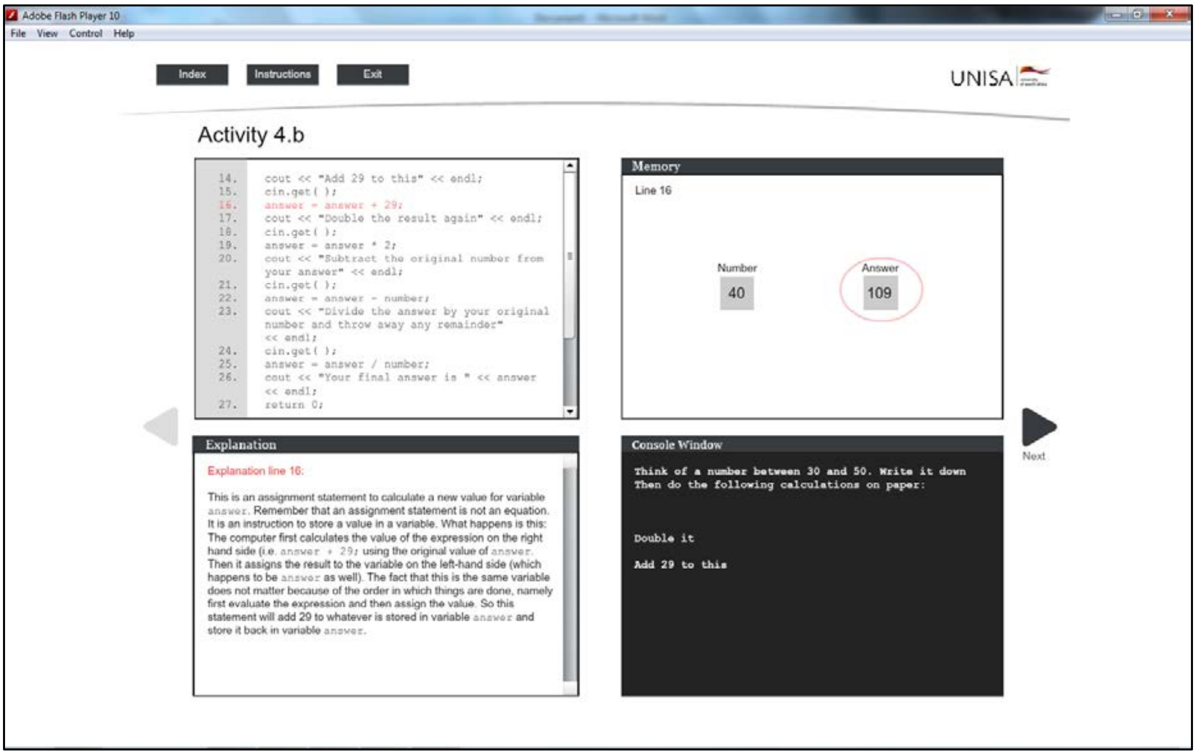
Explanation line 15:

Another `cin.get( );` to remove one keystroke from the input stream `cin`, because the user pressed <Enter>.

Console Window

```
Think of a number between 30 and 50. Write it down
Then do the following calculations on paper:


Double it

Add 29 to this
```

Figure 5.12 Screenshot of activity 4.b while executing line 15



Activity 4.b

```
14.  cout << "Add 29 to this" << endl;
15.  cin.get( );
16.  answer = answer + 29;
17.  cout << "Double the result again" << endl;
18.  cin.get( );
19.  answer = answer * 2;
20.  cout << "Subtract the original number from
     your answer" << endl;
21.  cin.get( );
22.  answer = answer - number;
23.  cout << "Divide the answer by your original
     number and throw away any remainder"
     << endl;
24.  cin.get( );
25.  answer = answer / number;
26.  cout << "Your final answer is " << answer
     << endl;
27.  return 0;
```

Memory

Line 16

Number	Answer
40	109

Explanation

Explanation line 16:

This is an assignment statement to calculate a new value for variable `answer`. Remember that an assignment statement is not an equation. It is an instruction to store a value in a variable. What happens is this: The computer first calculates the value of the expression on the right hand side (i.e. `answer + 29;` using the original value of `answer`. Then it assigns the result to the variable on the left-hand side (which happens to be `answer` as well). The fact that this is the same variable does not matter because of the order in which things are done, namely first evaluate the expression and then assign the value. So this statement will add 29 to whatever is stored in variable `answer` and store it back in variable `answer`.

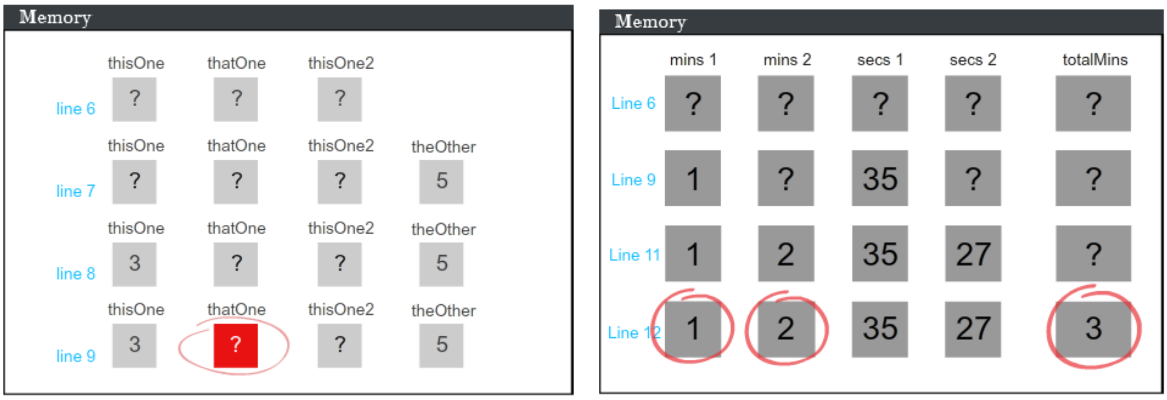
Console Window

```
Think of a number between 30 and 50. Write it down
Then do the following calculations on paper:


Double it

Add 29 to this
```

Figure 5.13 Screenshot of activity 4.b while executing line 16

where the execution history is shown with the variable diagrams showing values of the variables in previous statements, the need for implementing Guideline 22 becomes apparent.

Another point of debate was whether the variable names in the Memory box should appear above each line or only above each column. Both options were implemented and while testing the first activities, it became immediately clear that variable names should be displayed above each line in the Memory box, since displaying names only above each column, forces the user to look upwards to determine the name of a variable after a few lines have been executed. This increases the cognitive load and distracts attention and comprehension. It also makes it impossible to track parameter transfer when functions are executed. See for example the two views of the Memory box in Figure 5.14.



Memory

	thisOne	thatOne	thisOne2	
line 6	?	?	?	

	thisOne	thatOne	thisOne2	theOther
line 7	?	?	?	5

	thisOne	thatOne	thisOne2	theOther
line 8	3	?	?	5

	thisOne	thatOne	thisOne2	theOther
line 9	3	?	?	5

Memory

	mins 1	mins 2	secs 1	secs 2	totalMins
Line 6	?	?	?	?	?
Line 9	1	?	35	?	?
Line 11	1	2	35	27	?
Line 12	1	2	35	27	3

Figure 5.14 Two views of the Memory box, the first with variable names shown above each variable diagrams, and the second with variable names only on top of the first variable diagram for a variable.

5.4.4.2 Lessons learnt during the testing of the tutorial

The initial testing of the tutorial before rolling it out to students was done by the designer. This had to be rigorous for the following reasons: the student corps to which the tutorial was given was quite large (up to 3 000 students per semester); a team, instead of only one developer was used; and the team of developers did not consist of programmers.

The researcher found that the tutorial had to be verified on four different levels, which are frequently interwoven, as described below:

1. Content

This required verifying that the content given to the developers had been correct and that they implemented it correctly in the tutorial, that is that the explanations, variable diagrams and output/input corresponded with the program code and interpreted it correctly.

The four boxes should reflect the state of the same statement at any one time. In other words, when a specific statement is highlighted in the Program Code box, that statement should be explained in the Explanation box, the changes in the Memory box should reflect changes in memory due to this specific statement and the output produced or input required by the statement should be shown in the Console Window box.

Variable diagrams should only change for the statements in the program code that cause a change in computer memory. Only the variable diagrams for those variables whose values are affected, should change, while the values for the other variables available in memory at that stage, stay the same. In addition, the change in value has to correspond to the program statement being imitated or ‘executed’.

2. Sequence: execution order

The execution order had to be checked to ensure that the activity is executed in the same order as the program statements, including function calls and returns. This meant that program logic should be reflected correctly when the *Next* button is used to step through the program, as well as checking that the Back button still produces the correct sequence when steps are traced backward.

In addition, when the user has to choose between two options, the correct explanation should be displayed, and execution should continue at the correct follow-up statement. Furthermore, this sequence should still hold when the *Back* button has been used.

3. Format

Checking the format required checking the appearance of all four boxes.

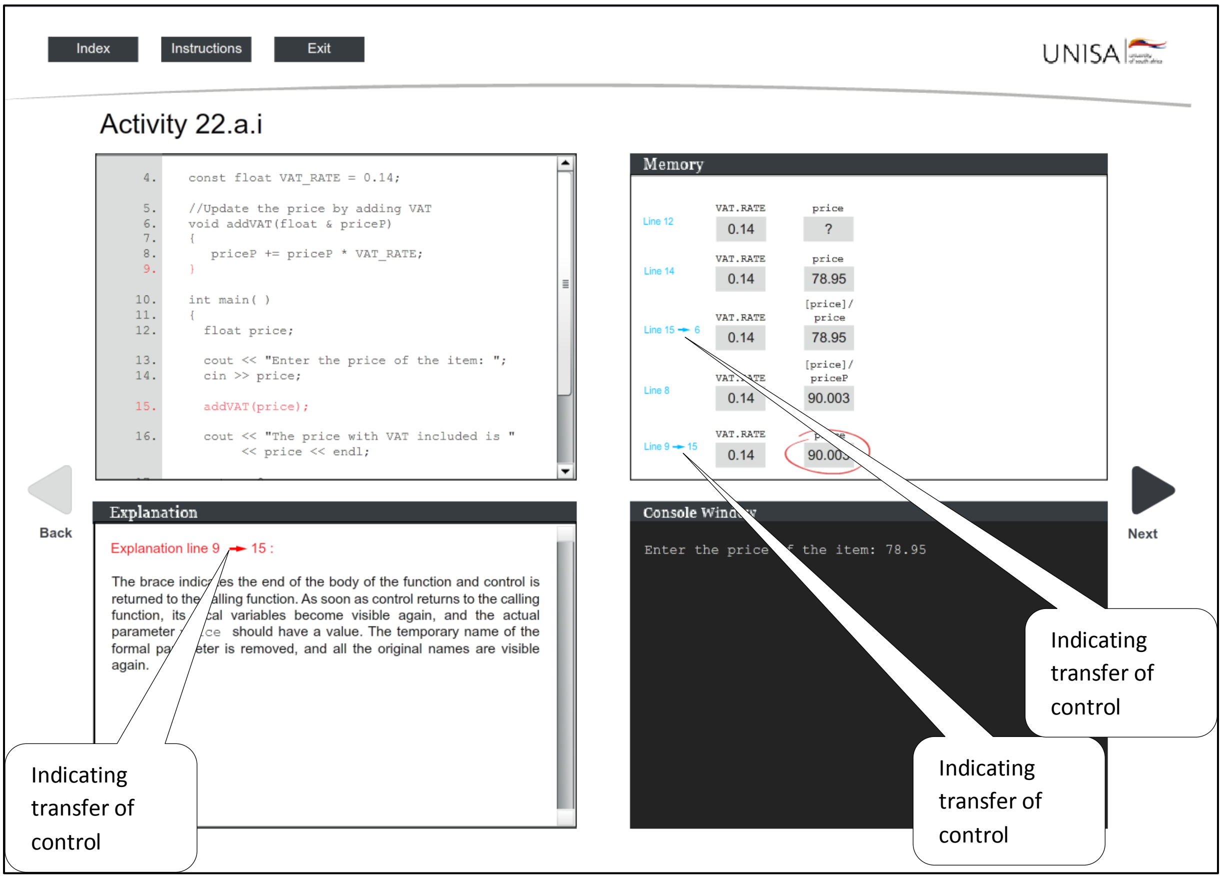
In the Program Code box the indentation had to be correct and program statements had to follow the correct syntax. The statement being ‘executed’ or simulated should be highlighted in red. Where statements span more than one line, all the relevant lines should be highlighted. For function calls, both the statement where the function call occurs as well the function signature should be highlighted, and both should be visible. Similarly, for function returns, both the return statement and the original calling statement should be highlighted and visible. If both cannot be shown simultaneously in the Program Code box, a button with a message to allow the user to move between the two relevant statements should be available in the Explanation box.

In the Explanation box font Arial was used for explanations and, as is convention, Courier New for program code statements. Prompts in the Explanation box direct the user’s attention to changes in the Memory box and the Console Window. All prompts should be in blue and in a consistent format. Therefore both the format of the text had to be verified, as well as that of the prompts.

In the Memory box the name of the variable should appear above its variable diagram, and the line number should appear to the left of all the variables in memory available to the program (visible) at that stage. When a function call or return is executed, the transfer of control in program execution should be indicated in the line numbers in the Memory box, such as for instance ‘Line 15 → 6’ when a function is executed or ‘Line 9 → 15’ when control returns to the main function (see Figure 5.15). Value and reference parameters, as well as inaccessible variables during function execution have to be denoted correctly. Prompts to changes in the Memory box should all be in the form of red circles around the relevant variable diagrams.

In the Console Window box the output had to correspond to the program statements in both content and format. Similarly, input (if presented) had to be indicated in the Console Window box, and be in the correct format. The cursor should also appear (as a blinking dash) in the correct position in the Console Window box.

A very important aspect that had to be checked was to ensure that changes in the Memory box and Console Window box did not change the previous contents of these two boxes because this would portray an inaccurate picture of the tracing process.


Index
Instructions
Exit
UNISA
Back
Next
Indicating transfer of control
Indicating transfer of control
Indicating transfer of control

Activity 22.a.i

```
 4.   const float VAT_RATE = 0.14;

 5.   //Update the price by adding VAT
 6.   void addVAT(float & priceP)
 7.   {
 8.      priceP += priceP * VAT_RATE;
 9.   }

10.   int main( )
11.   {
12.     float price;

13.     cout << "Enter the price of the item: ";
14.     cin >> price;

15.     addVAT(price);

16.     cout << "The price with VAT included is "
             << price << endl;
```

Memory

Line 12
VAT.RATE 0.14
price ?

Line 14
VAT.RATE 0.14
price 78.95

Line 15 → 6
VAT.RATE 0.14
[price]/ price 78.95

Line 8
VAT.RATE 0.14
[price]/ priceP 90.003

Line 9 → 15
VAT.RATE 0.14
price 90.003

Explanation

Explanation line 9 → 15 :

The brace indicates the end of the body of the function and control is returned to the calling function. As soon as control returns to the calling function, its local variables become visible again, and the actual parameter price should have a value. The temporary name of the formal parameter is removed, and all the original names are visible again.

Console Window

```
Enter the price of the item: 78.95
```

Figure 5.18 Indicating transfer of control in program execution

4. Didactics

On a didactic level the necessary prompts to direct students' attention to changes in the variable diagrams (in the Memory box) and Console Window box should be displayed in the correct position and at the correct moment and statement. These prompts are given in the Explanation box as blue text, and in the Memory box as red circles around relevant variable diagrams.

Prompts have to be in a consistent format to reduce cognitive load, and this had to be verified too.

Part of verifying the didactic requirements were ensuring that students can see both the statement where a function call occurs as well as the signature of the function, and that, if that is not possible, a button in the Explanation box provides the opportunity to move between the calling statement and the function signature. The same applies for the function returns.

As can be seen from the above, the initial testing and verification of a PV tool before rolling it out for use by the students is an essential and crucial part of the development.

5.4.5 Further guidelines

From the development process and initial testing of the tutorial as described here, the following four general guidelines for the design and development of visualizations to enhance comprehension are identified:

1. Deliberately build in elements to help students consolidate their mental model, such as presenting all four panels for a statement simultaneously on the same screen (following the contiguity principle, Guideline 9) to enable them to integrate the information provided by these four views. Numbering the statements in the Program Code box, the Explanation box and the Memory box also assists with this process, as do labeling the iterations in loops. Showing changes in variable diagrams in the Memory box only when changes in the internal memory occur, and imitating the Console Window of the compiler to show output, serve the same purpose.
2. Reduce extraneous cognitive load as much as possible. A number of the guidelines in the framework are specifically intended to reduce extraneous cognitive load, namely Guidelines 10 (the modality principle), 12 (flexible execution control) and 24 (scaffolding). Using cues consistently (Guideline 15), and using signaling to draw attention to important changes (Guideline 17) also contributes to this purpose. Other elements in the tutorial intended to reduce the extraneous cognitive load include the numbering of statements in the Program Code box, the Explanation box and the Memory box; and changing variable diagrams only with changes in the internal memory.
3. Prompt the user judiciously, that is neither too much nor too little. For example, using option 2 in Figure 5.11 (a flashing red background in the variable diagram box, with the value displayed in black and a red circle around the variable diagram) to cue users to look at changes in the Memory box, would be an overkill, while displaying variable names only above each column instead of above each line in the Memory box, would offer too little information.
4. Stringent testing of the PV tool with particular attention paid to verifying aspects of the PV tool on four different levels, namely content; sequence and execution order; format; and didactics should be done before providing it to students, as can be seen from section 5.5.5.2.

This enhances Guideline 25 in the framework (performing user testing on each animation before using it for instruction), and also follows the principles of human-computer interaction.

Concerning the development process itself, it is recommended that the developers of visualizations work together in the same venue to facilitate uniformity in the implementation. They should also consult with the main designer before making design decisions regarding the implementation of the visualization.

5.5 Summary and conclusion

This chapter presents the last part of the literature review for this study, namely guidelines from literature for using and creating visualization tools effectively, in section 5.2. Guidelines from three research areas, CER, educational psychology and computer graphics, are discussed. These guidelines were converted to a framework of 26 guidelines for developing and creating visualization tools for teaching programming in section 5.3.

Several of the guidelines occur in two or all three of the research areas. In such cases the guideline was synthesized into a single guideline. The guidelines are enhanced with reasons or explanations for their recommendation, as well as considerations that should be taken into account when implementing a guideline. Most of the reasons, explanation and considerations given come from the fields of educational research and computer graphics. Some considerations may rule out applying certain guidelines, which may allow lecturers to develop visualizations that engage learners more effectively.

The design and development of the tutorial to teach tracing is described in section 5.4 as part of the second phase (Development of solutions informed by existing design principles and technological innovations) in the design-based research approach followed. The framework presented in section 5.3 is used as the theoretical framework to guide the design of the tutorial. The tutorial itself is described in section 5.4.1. The description includes the tutorial specifications as well as the activities in the tutorial and their implementation. The screen layout is shown and a typical run demonstrated by showing the screens as a specific statement is 'executed'. The cueing to guide students' attention and navigation through the tutorial are also described.

In section 5.4.2 the design decisions taken in developing the tutorial are discussed and related to the guidelines in the framework from section 5.3. The ODL environment at Unisa played a significant role in several design decisions. The development process itself and the initial testing are described in section 5.4.3. Section 5.4.5 relates lessons learned during the development and testing of the tutorial. Four general guidelines for the development of PVs are also identified and presented in section 5.4.5. Together with the framework presented in section 5.3, these guidelines form part of the theoretical contribution of this PhD study.

The next chapter describes the first cycle in the third phase (iterative cycles of testing and refinement of solutions in practice) of the design-based research approach followed in this study.

Note to the reader regarding Chapters 6 and 7

The statistical analyses discussed in these chapters comprise several models. Chapter 6 describes the first implementation cycle of the Drawing Variable Diagrams tutorial in 2012, while Chapter 7 covers the second implementation cycle in 2013. In addition, the analysis for the first semester was repeated for the second semester. The following measures are implemented to improve readability:

1. The statistical analyses for the two semesters in each implementation cycle are usually discussed together. Graphs and tables are labelled clearly to indicate the semester and year it refers to.

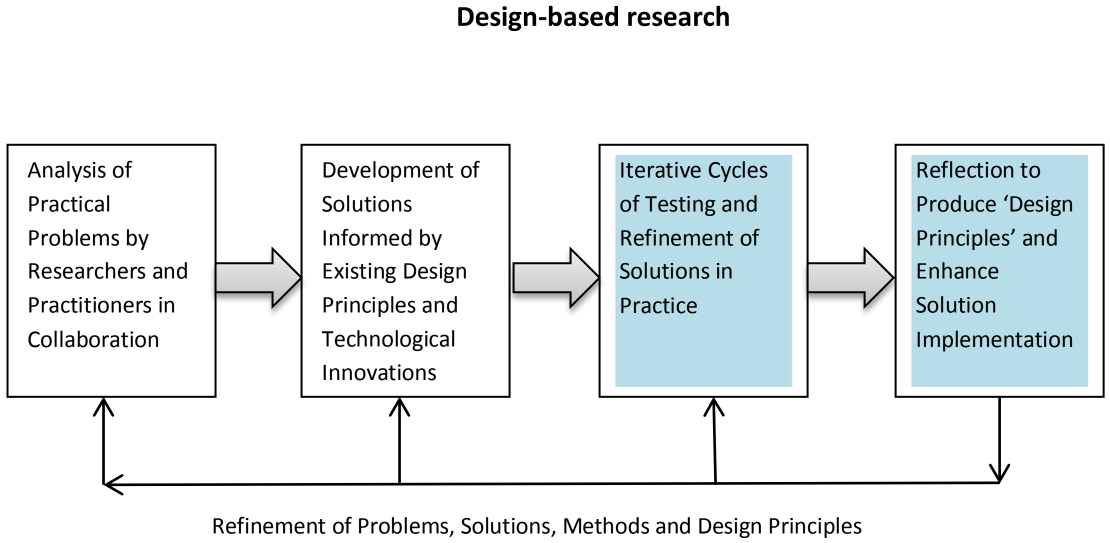
2. In cases where this is not feasible, a clear heading with a descriptive name for the model and the semester for which it has been fitted is used. Thereafter the name of the model, the year or the semester for which it is fitted, are sometimes omitted for the sake of readability.

3. Some supporting graphs and tables have been placed in Appendix D. All tables and graphs in Appendix D are clearly labelled with the semester to which it applies, and provided with a heading corresponding to the heading in the chapter. The section number as used in the chapter is also supplied in brackets after the heading.

4. On occasion a local smoother is included in the fit of a model to show that the fit is not linear. In these cases a small legend, which will not be mentioned in the accompanying discussion, is included in the display.

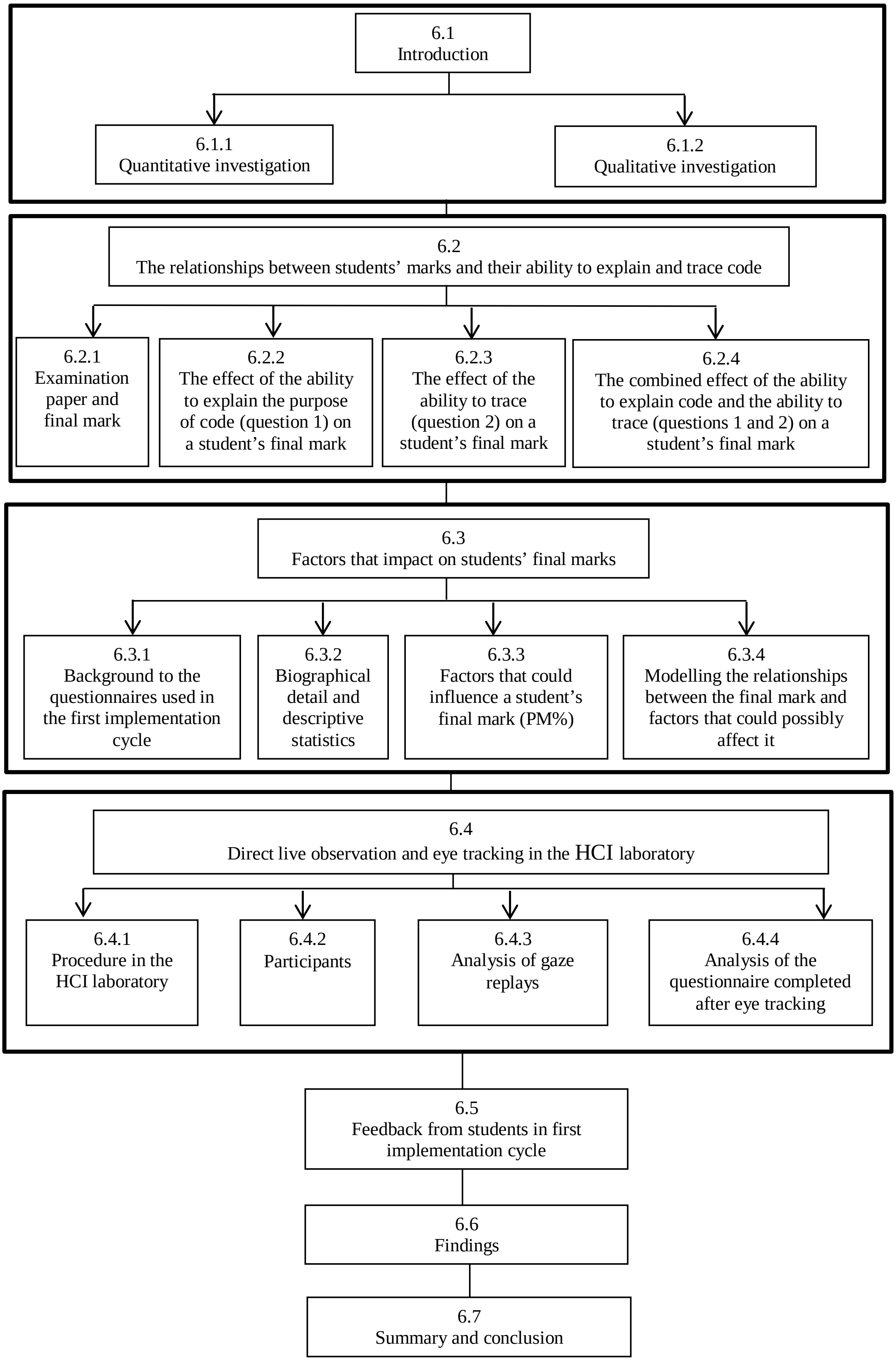
5. The statistical analyses were done by a trained statistician and all assumptions for statistical techniques were tested and satisfied.

Design-based research phase covered in Chapter 6


Design-based research
Analysis of Practical Problems by Researchers and Practitioners in Collaboration
Development of Solutions Informed by Existing Design Principles and Technological Innovations
Iterative Cycles of Testing and Refinement of Solutions in Practice
Reflection to Produce 'Design Principles' and Enhance Solution Implementation
Refinement of Problems, Solutions, Methods and Design Principles

Phase	**Element**	**Position**
Phase of design-based research (Reeves, 2006)	*Topics/elements that need to be addressed*	*Position in this thesis*
PHASE 1: Analysis of practical problems by researchers and practitioners in collaboration	Statement of problem	Chapter 1, Section 1.3.1 Chapter 4, Section 4.3.2.1
	Consultation with researchers and practitioners	Chapter 4, Section 4.3.2.1 and section 4.3.4.3
	Research questions	Chapter 1, Section 1.3.3 Chapter 4, Section 4.3.2.3
	Literature review	Chapters 2 and 3, Section 5.2
PHASE 2: Development of solutions informed by existing design principles and technological innovations	Theoretical framework	Chapter 5, Section 5.2
	Development of draft principles to guide the design of the intervention	Chapter 5, Section 5.3
	Description of proposed intervention	Chapter 5, Section 5.5
PHASE 3: Iterative cycles of testing and refinement of solutions in practice	Implementation of intervention (First iteration) Participants Data collection Data analysis	Chapter 6
	Implementation of intervention (Second and further iterations) Participants Data collection Data analysis	Chapter 7
PHASE 4: Reflection to produce 'design principles' and enhance solution implementation	Design principles	Chapters 5, 6 and 7
	Designed artefact(s)	Available on course website
	Professional development	Chapter 8

Map of Chapter 6 (First implementation cycle of the Drawing Variable Diagrams Tutorial)


6.1 Introduction
6.1.1 Quantitative investigation
6.1.2 Qualitative investigation
6.2 The relationships between students' marks and their ability to explain and trace code
6.2.1 Examination paper and final mark
6.2.2 The effect of the ability to explain the purpose of code (question 1) on a student's final mark
6.2.3 The effect of the ability to trace (question 2) on a student's final mark
6.2.4 The combined effect of the ability to explain code and the ability to trace (questions 1 and 2) on a student's final mark
6.3 Factors that impact on students' final marks
6.3.1 Background to the questionnaires used in the first implementation cycle
6.3.2 Biographical detail and descriptive statistics
6.3.3 Factors that could influence a student's final mark (PM%)
6.3.4 Modelling the relationships between the final mark and factors that could possibly affect it
6.4 Direct live observation and eye tracking in the HCI laboratory
6.4.1 Procedure in the HCI laboratory
6.4.2 Participants
6.4.3 Analysis of gaze replays
6.4.4 Analysis of the questionnaire completed after eye tracking
6.5 Feedback from students in first implementation cycle
6.6 Findings
6.7 Summary and conclusion

Chapter 6 First implementation cycle of the Drawing Variable Diagrams Tutorial

6.1 Introduction

As shown in Table 4.3, the third phase of the design-based approach followed in this study consisted of two iterative cycles of testing and refinement of the tutorial to teach students to draw variable diagrams. The development of the tutorial itself has been discussed in Chapter 5.

This chapter, together with Chapter 7, addresses the second, third and fourth research questions, namely:

1. Will a tutorial to teach tracing to visualize program execution and parameter transfer, based on the framework of guidelines, assist students in acquiring programming skills in an ODL environment so that it is noticeable in average marks?
2. How do students' biographical properties, their positive user experience, their use of tracing and the extent and manner of tutorial use, affect their ability to acquire programming skills in an ODL environment?
3. What lessons have been learnt through the practical testing and refinement of the visualization tool?

This chapter describes the first cycle in the testing and refinement of the tutorial to teach students to draw variable diagrams which took place during 2012. This included both a quantitative and a qualitative investigation. The quantitative investigation in particular, aims at answering the second and third questions, while the reflection on the data analysis together with the qualitative investigation answers question 4. In section 6.1.1 a background to the quantitative investigation is provided, and in section 6.1.2, the same is done for the qualitative investigation. The quantitative investigation itself is described in sections 6.2 and 6.3, while the qualitative investigation is covered in sections 6.4 and 6.5. The findings from this implementation cycle are discussed in section 6.6, and in section 6.7 the summary and conclusion of the chapter is presented.

6.1.1 Quantitative investigation

The data collection for the quantitative investigation comprised the following two aspects:

- Examination marks for each student.
- An optional multiple-choice questionnaire containing questions on biographical data and previous experience, how students used the tutorial and their experience of using the tutorial.

The student number was used to link the information collected from each questionnaire to the same student's examination mark. More detail about the data collected for the quantitative investigation is provided as background when its analysis is discussed. The SPSS statistical analysis software was used to analyse the data.

The reader is reminded that due to ethical reasons (no student could be prevented access to the tutorial – see section 4.3.5.3) a control group could not be used. Instead factor analysis was done to determine the effect of a number of factors, one of which was students' use of the tutorial, on their final marks. The factor analysis was done on both students who have used the tutorial and those who did not.

Not all of the respondents were included in the statistical analysis for the following reasons:

- Respondents completed the questionnaire and the answers to Assignment 1, a multiple-choice question assignment, on the same mark reading sheet. Respondents who completed the mark reading sheet incorrectly by answering the multiple choice assignment questions, instead of the questionnaire items, were excluded.
- Since it was expected that both students' marks for Mathematics and English might have influenced their final mark, only students for whom marks for Mathematics and English could be obtained from the Unisa student system were included in the analysis.
- Respondents who did not submit both assignments and who did not write the examination at the end of the semester, were excluded, since both these aspects influenced the final mark (the dependent variable in the statistical analyses). The final mark was comprised from the year mark and the examination mark. The year mark consisted of the marks obtained for assignments submitted.

During the first semester 475 respondents satisfied the criteria to be included in the statistical analysis and in the second semester 532 respondents satisfied these criteria.

The quantitative investigation aimed to answer the second and third research questions, as listed above. To determine whether an improved ability to trace, would have an effect on a student's final mark, the relationships between students' ability to explain the purpose of code and to trace, as well as the combination of students' ability to explain code and to trace, and their final marks, were investigated. This is examined in section 6.2.

Students' responses to the multiple-choice questionnaire were then used to investigate the factors that impacted on their final marks in this study. This was done by categorising responses to the questionnaire according to probable explanatory effects on students' final marks, and modelling the relationships between these factors and the final marks in section 6.3.

6.1.2 Qualitative investigation

The purpose of the qualitative investigation was to evaluate the user interface and find usability problems in the design (Nielsen, 1994) to increase the effectiveness and utility of the designed intervention. It was also intended to shed further light on the findings of the quantitative investigation. The qualitative investigation comprised two parts, namely –

- direct live observation and eye tracking in a HCI laboratory; and
- written feedback from students on the COS1511 forum.

The direct live observation while using the tutorial combined with eye tracking, included a retrospective comprehension test as well as a questionnaire with open-ended, semi-structured questions that students completed after the eye tracking and observation. Data for written feedback from COS1511 students, were obtained by initiating a topic on the COS1511 discussion forum that requested feedback from students on reasons why they found the tutorial either helpful or frustrating.

The qualitative investigation aimed to contribute to the answer to research question 4. It also shed more light on the results obtained in the quantitative investigation for research question 3. In section 6.4, the direct live observation and eye tracking conducted in the HCI laboratory are described, and in section 6.5 feedback received from students on the online forum for COS1511, is reported.

6.2 The relationships between students' marks and their ability to explain and trace code

The BRACElet project found a positive correlation in performance between 'explain in plain English' tasks and code writing tasks, as well as between code tracing and code writing tasks (Lister et al., 2009; Lopez et al., 2008). They also found that a combination of skill in code explanation and tracing skills, predicts performance in code writing (Venables et al., 2009).

Based on these findings, the premise for this research was that improving students' tracing skills would improve their programming skills and therefore their average marks. In order to confirm that this also holds for the student cohort used in this research, the relationships between students' abilities to explain the purpose of code and to trace, and their final marks, were investigated. The purpose was to determine whether their ability to explain code or trace affected their final marks. The *combination* of students' ability to explain code and to trace was also investigated to establish whether this affected their final marks. The final mark for each student, comprised of the sum of the marks for the MCQs in Part A and the questions in Part B of the examination paper, plus the year mark (represented by PM% in the statistical analysis), was used as dependent variable in the analysis. The analysis included both students who used the tutorial as well as students who did not use the tutorial.

Students could learn to trace by studying the relevant sections in the Study Guide for COS1511 or by using the tutorial. As discussed in section 5.5.1.2, the activities in the tutorial show how to trace each new programming construct or concept taught in the Study Guide.

The relationships between students' marks and their ability to explain and trace code are presented below in terms of students' examination papers and final marks; the effect of the ability to explain the purpose of code (question 1) on a student's final mark; the effect of the ability to trace (question 2) on a student's final mark; and the combined effect of the ability to explain code and the ability to trace (questions 1 and 2) on a student's final mark.

6.2.1 Examination paper and final mark

Examination marks for each student were obtained from the Unisa student system after each examination. The examination paper for both semesters in 2012 used the same structure: in Part A, ten MCQs (20 marks) had to be answered on a mark reading sheet, and in Part B, eight questions had to be answered on paper for a total of 70 marks. Part A was marked electronically and the researcher did not have access to answers for individual questions in Part A. Unisa's examination system combined the results for Part A automatically with the results from Part B once the scripts for Part B had been marked. Table 6.1 shows the topics and mark allocation for each of the 8 questions in Part B of the examination paper. Part A of the examination paper contributed 20% to the final mark and Part B contributed 70%. The year mark obtained from assignments submitted, contributed the additional 10% to a student's final mark.

Table 6.1 Structure: Part B of COS1511 examination papers in 2012

Question number	Topic	Marks allocated
1	Explain the purpose of two short code fragments.	4
2	Use variable diagrams to trace parts of two programs (a program using the `switch` statement and a program call to a function with value and reference parameters), and indicate what the output will be.	11
3	Complete a program by writing nested `if` statements.	8
4	Complete a program by writing a `while` loop and `if` statement.	8
5	Answer questions on value and reference parameters; and write and call a small function.	10
6	Write a complete program that uses a two dimensional array and functions to calculate totals and averages for each row in the array.	17
7	Define a struct, an array of structs and write statements to access components of a struct in the array.	6
8	Short questions in which students had to use string member functions.	6

Table 6.2 shows the mean percentages and standard deviations achieved by respondents for questions 1 to 8 in Part B of the two semester examinations in 2012. Semester 1 participants consistently did better than semester 2 participants in all questions. In semester 1, question 3 (writing nested `if` statements) had the highest mean percentage, while question 1 (explain code in plain English) had the second-highest mean percentage, and question 4 (completing a program by writing a `while` loop and `if` statement) the third-highest. In semester 2, question 1 (explain code in plain English) had the

highest mean percentage, question 3 (writing nested `if` statements) the second highest and question 2 (tracing) the third-highest.

Table 6.2 Mean percentages and standard deviations of marks achieved by respondents for questions 1 to 8 in Part B of the two semester examinations in 2012.

	Semester 1 2012 **N= 475**		**Semester 2 2012** **N= 532**	
	Mean	**Std Dev**	**Mean**	**Std Dev**
Q1 %	58.8	37.0	55.7	30.5
Q2 %	53.3	32.6	49.6	30.0
Q3 %	65.9	34.4	54.8	40.1
Q4 %	57.4	40.4	38.9	32.4
Q5 %	47.7	37.1	38.6	36.6
Q6 %	30.5	29.9	29.6	30.2
Q7 %	37.8	36.9	34.1	33.6
Q8 %	21.1	30.3	17.0	27.4

For the first semester in 2012 the final marks varied from a lowest mark of 0% to the highest mark of 100% with the median of 48.89%. The mean for the final marks for the first semester 2012 was 47.45% and the standard deviation 27.26. For the second semester the final marks varied from a lowest mark of 5.56% to the highest mark of 97.78% with a median of 38.33%. The mean for the second semester 2012 was 42.38% and the standard deviation 23.65. Supporting tables are shown in Appendix D.1.1.

6.2.2 The effect of the ability to explain the purpose of code (question 1) on a student's final mark

Spearman correlation tests were conducted to determine whether there exists relationships between the marks achieved for questions 1 to 8 in Part B of the examination papers for both semesters. In both cases it confirmed that all of the marks have a significant and positive relationship with each other. (See Tables D.1.3 and D.1.4 in Appendix D.)

To determine the effect of the ability to explain the purpose of code (question 1) on the final mark for a student (PM%), a simple linear regression was done with PM% as dependent variable and Q1 (the mark for question 1) as independent variable, for both semesters.

The model for the first semester is statistically significant with a p-value of less than 0.01, indicating a level of 99% of confidence ($F_{1,474} \approx 336.0918$; $p < 0.0001$). The model for the second semester is also statistically significant with a p-value of less than 0.01, indicating a level of 99% of confidence ($F_{1,531} \approx 198.7560$; $p < 0.0001$). Students' marks for question 1 (their ability to explain the purpose of code) for Part B of the examination paper, explain 41.53% of the variance in examination marks for the first semester, and 26.36% of the variance in examination marks for the second semester, indicating a reasonable fit in both cases.

Figure 6.1 shows the fit of PM% by question 1 in Part B of the examination paper for the *first* semester and Figure 6.2 shows the fit of PM% by question 1 in Part B of the examination paper for the *second* semester. In both cases a higher mark for question 1 is associated with a higher final mark, indicating that students who could explain code achieved a better final mark. Supporting tables for both semesters are shown in Appendix D.1.2.

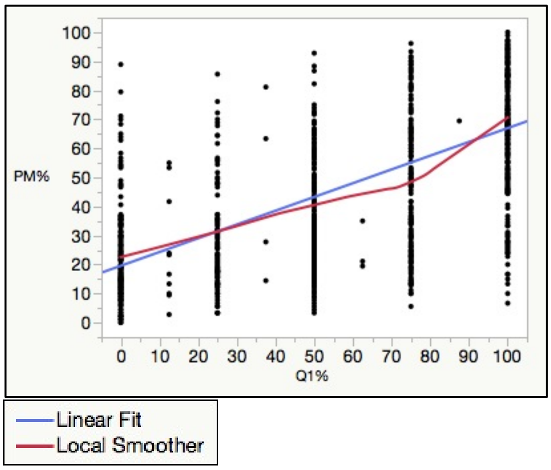


Figure 6.1 Simple linear regression fit of PM% by Q1 semester 1 2012

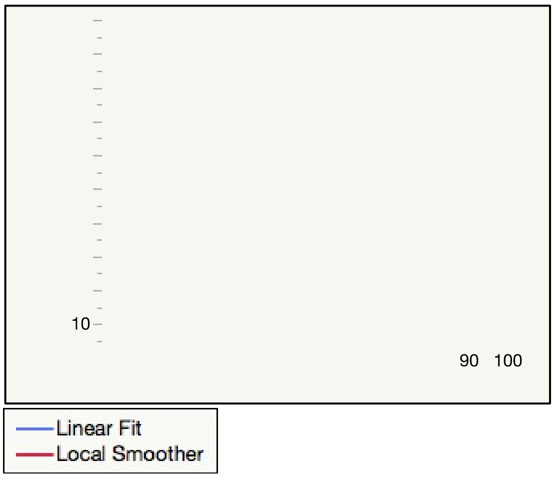


Figure 6.2 Simple linear regression fit of PM% by Q1 semester 2 2012

6.2.3 The effect of the ability to trace (question 2) on a student's final mark

To determine the effect of a student's ability to trace (question 2) on the final mark for a student (PM%) another simple linear regression was done with PM% as dependent variable and Q2 (the mark for question 2) as independent variable, for both semesters.

The model for the first semester in 2012 is statistically significant with a p-value of less than 0.01, indicating a level of 99% of confidence ($F_{1,474} \approx 976.4527$; $p < 0.0001$). The model for the second semester is also statistically significant with a p-value of less than 0.01, indicating a level of 99% of confidence ($F_{1,531} \approx 825.9361$; $p < 0.0001$). Students' marks for question 1 (their ability to explain the purpose of code) for Part B of the examination paper, explain 63.37% of the variance in examination marks for the first semester, and 60.91% of the variance in examination marks for the second semester, indicating a good fit in both cases. Supporting tables for both semesters are shown in Appendix D.1.3.

Figure 6.3 shows the fit of PM% by question 2 in Part B of the examination paper for the *first* semester 2012 and Figure 6.4 shows the fit of PM% by question 2 in Part B of the examination paper for the *second* semester 2012. In both cases a higher mark for question 2 is associated with a higher final mark, indicating that students who could trace achieved a better final mark.

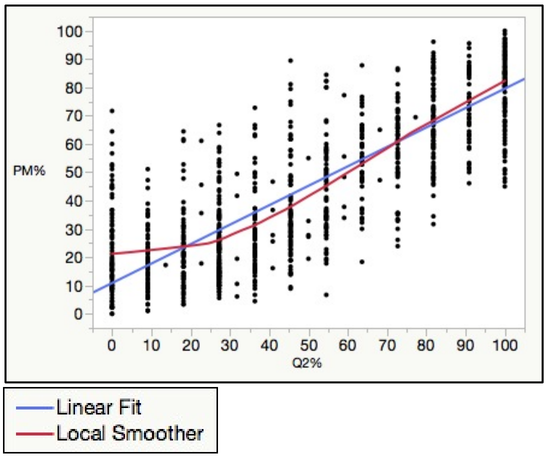


Figure 6.3 Simple linear regression fit of PM% by Q2 semester 1 2012

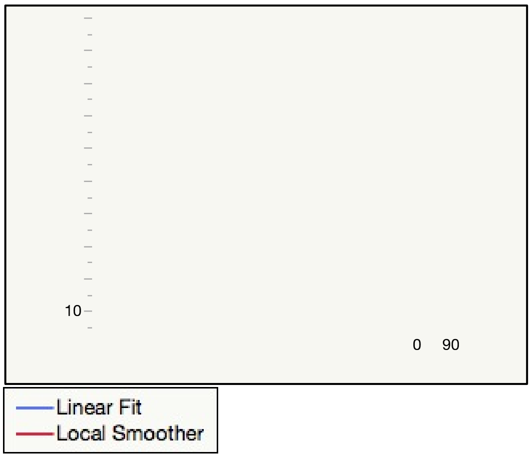


Figure 6.4 Simple linear regression fit of PM% by Q2 semester 2 2012

6.2.4 The combined effect of the ability to explain code and the ability to trace (questions 1 and 2) on a student's final mark

To investigate the combined effect of the ability to explain code and the ability to trace (questions 1 and 2), on the final marks, the relationships between question 1 and question 2 and the final marks were modelled on all the data. The final mark for each student was used as the dependent variable in this analysis. Multiple linear regression was used to fit the models for both semesters.

The model for the *first* semester in 2012 is statistically significant with a p-value of less than 0.01, indicating a level of 99% of confidence ($F_{3,474} \approx 434.5630$; $p < 0.0001$). The parameter estimates for the T-test in Table 6.3 shows that both question 1 ($p < 0.0001$) and question 2 ($p < 0.0001$) are significant predictors, as well as the combined effect of questions 1 and 2 ($p = 0.0119$). The independent variables in the whole model for the combined effect of question 1 and question 2 explain 73.46% of the variance in examination marks for the first semester, indicating a good fit.

Table 6.3 Parameter estimates for the full model for the effect of question 1 and question 2 on PM% semester 1 2012

Term	Estimate	Std Error	t Ratio	Prob>|t|	Std Beta	VIF
Intercept	4.0837953	1.448763	2.82	0.0050*	0	.
Q1	0.2177441	0.021016	10.36	<.0001*	0.2959	1.4475028
Q2	0.5551369	0.023637	23.49	<.0001*	0.663248	1.4153812
(Q1%-58.8158)*(Q2%-53.2727)	0.0015247	0.000604	2.52	0.0119*	0.060745	1.0272817

The model for the *second* semester is also statistically significant with a p-value of less than 0.01, indicating a level of 99% of confidence ($F_{3,531} \approx 341.1209$; $p < 0.0001$). The parameter estimates of the T-test in Table 6.4 shows that both question 1 ($p < 0.0001$) and question 2 ($p < 0.0001$), as well as the interaction between questions 1 and 2 ($p = 0.0005$) are significant predictors. The independent variables in the whole model for the effect of question 1 and question 2 for the second semester explain 65.97% of the variance in examination marks for the second semester, indicating a good fit.

Table 6.4 Parameter estimates for the full model for the effect of question 1 and question 2 on PM% semester 2 2012

Term	Estimate	Std Error	t Ratio	Prob>|t|	Std Beta	VIF
Intercept	5.0288562	1.398051	3.60	0.0004*	0	.
Q1 %	0.1809	0.021731	8.32	<.0001*	0.233035	1.2156986
Q2 %	0.5308628	0.022183	23.93	<.0001*	0.673644	1.2293121
(Q1 %-55.6861)*(Q2 %-49.5813)	0.0025155	0.000717	3.51	0.0005*	0.089798	1.01499

Supporting tables and graphs for both semesters are shown in Appendix D.1.4.

The prediction profilers for the full model for both semesters in Figure 6.5 and Figure 6.6 show clearly that both question 1 (explaining code in plain English) and question 2 (tracing) had a positive effect on a student's final mark.

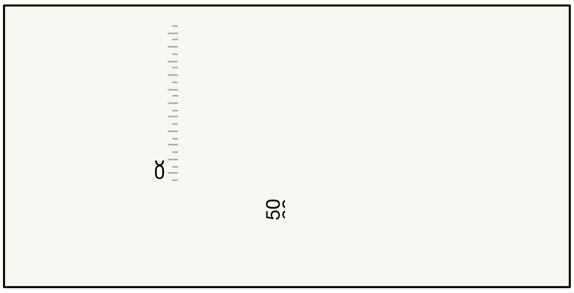


Figure 6.5 Prediction Profiler for the combined effect of question 1 and question 2 on PM% semester 1 2012

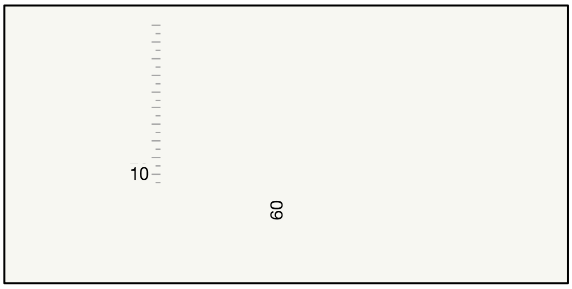


Figure 6.6 Prediction Profiler for the combined effect of question 1 and question 2 on PM% semester 2 2012

The ability to trace however, had a stronger association with the final mark than the ability to explain code in plain English. The interaction between question 1 (explaining code in plain English) and question 2 (tracing), also had an effect on the final mark of a student, although it was less than the individual questions. Therefore, the ability to explain code and to trace as well as the combined effect thereof had an effect on the final mark of students, although the combined effect was less than the individual effects.

Following the above, the results of determining the relationships between students' marks and their ability to explain and trace code, both for students who used the tutorial as well as students who did not use the tutorial, can be summarised as follows:

- The results of the statistical analysis for both semesters in 2012, were similar; and confirm the findings of the BRACElet project that there exists a positive correlation between students' ability to explain the purpose of code and to trace, and their final marks (Lister et al., 2009; Lopez et al., 2008; Venables et al., 2009). The combination of students' ability to explain code and to trace, also affected their marks positively in both semesters.
- In both semesters the association between the ability to trace had a stronger association with the final mark than the ability to explain code in plain English. The mean percentages for question 1 (58.8% and 55.7% respectively) were higher than the mean percentages for question 2 (53.3% and 49.6%). However, the mark allocation for question 2 carried a greater

weight (11/70) than question 1 (4/70) which explains the reason why question 2 (ability to trace) had a higher effect than question 1 (ability to explain code in plain English) on the final mark of a student. This may have skewed the statistical results, nevertheless the results of this analysis confirms that an improved ability to trace should have a positive effect on a student's final mark.

In the next section, a number of factors that may have impacted on students' final marks are investigated.

6.3 Factors that impact on students' final marks

A number of factors that may have a positive influence on introductory programming students' performance were identified in the literature. These include –

- formal training or prior experience as a programmer (Byrne & Lyons, 2001; Wilson & Shrock, 2001);
- existing problem-solving skills developed in subjects such as Mathematics and Science (Bennedsen & Caspersen, 2005a; Chmura, 1998; Pillay & Jugoo, 2005; Wiedenbeck, 2005);
- past performance in Mathematics (Bergin & Reilly, 2006; Byrne & Lyons, 2001; White & Sivitanides, 2003; Wilson & Shrock, 2001); and
- programming behaviour such as time spent debugging (Watson, Li & Godwin).

On the other hand, Ventura Jr (2005) found no relationship between Mathematics marks and prior experience. Chmura (Chmura, 1998) noted that students with poor reading comprehension skills struggle to learn to program. Carter, Jernejcic and Lim (2007) found that students learning to program in their second or third language may experience a language barrier, since they have to continuously translate during lectures as well as while studying text books in a language other than their first language. Pillay and Jugoo (Pillay & Jugoo, 2005) observed that South-African students whose first language differ from the teaching language, achieved lower marks; while Gous and Roberts (2014) warn that students with a mother tongue other than English may be at a disadvantage. Concern about South-African students' reading ability also have been expressed by other researchers (Cliff, 2015; Gous & Roberts, 2014; Hefer, 2013; Kilfoil, 2008; Nel et al., 2004).

Students' responses to the multiple-choice questionnaire administered after they submitted their first assignment, were categorised according to probable explanatory effects on their final marks. The relationship between these factors and students' final marks were then investigated, by fitting various models on the data. The factors that may have impacted on students' final marks are presented below in terms of background information to the questionnaires used in the investigation, students' biographical detail and descriptive data, factors that could have influenced their final marks and models representing the relationship between these factors and students' final marks.

6.3.1 Background to the questionnaires used in the first implementation cycle

The questionnaires for the first and second semesters of 2012 are shown in Appendix B.1. Both questionnaires were included as the first part of the first assignment (a multiple choice assignment) since this assignment contained questions that were intended to compel the students to engage with the tutorial and drawing variable diagrams. The questionnaires included questions on biographical data (questions 1 to 8); students' computer literacy, their programming experience and registration for COS1511 (questions 9 to 11); questions related to their use of the tutorial and drawing variable diagrams (questions 12 to 16); and questions on their user experience (questions 17 to 21). Note that the questions on biographical data differ slightly in the two questionnaires (questions 3 to 8), in an attempt at greater clarity in the second semester.

Students were informed that completing the questionnaire was part of research on the usability and effectiveness of the tutorial to teach drawing variable diagrams; and that completing the questionnaire was optional. Nevertheless, a very good response rate was achieved. In the first semester 2 147 of the 2 877 students registered for COS1511 submitted assignment 1 and 1 231 students completed the questionnaire, giving a response rate of 42.8%. In the second semester 1 727 of the 1 921 students registered for COS1511, submitted assignment 1 and 1 000 students completed the questionnaire, giving a response rate of 52.1%. As explained in section 6.1, not all of these respondents were included in the statistical analysis. For the first semester of 2012, 475 (38.6%) and for the second semester 532 (53.2%) of the respondents were included in the statistical analysis.

Since the questionnaires were distributed to all students registered for COS1511, random sampling was not done. Instead it resulted in self-selection sampling (Oates, 2006). Being a nonprobability sample, it could be biased towards students in the COS1511 population who were available and willing to answer the questionnaire (Fowler Jr, 2009; Oates, 2006), so that normal assumptions for calculating sampling errors cannot be applied (Fowler Jr, 2009). Nonresponse can be a problematic cause for survey error, as "we lack good data about when nonresponse is and is not likely to be biased with respect to the content of the survey" (Fowler Jr, 2009:66). However, high response rates can reduce "the potential for error due to nonresponse to be important" (Fowler Jr, 2009:67).

The statistical analysis was done with the final mark for COS1511 (PM%) as the dependent variable, which reduced the population size to the number of students who wrote the examination. Therefore, the population size for the first semester in 2012 was 1 827 students and for the second semester in 2012 it was 1 267 (see Table 1.1 in section 1.1). Krejcie and Morgan (1970:608) provide a table to determine the sample size to be representative of a given population when random sampling is done, also used by Johnson and Christensen (2004:218). According to this table, for the first semester of 2012, when the population size was 1 827, 320 responses would have sufficed should random sampling have been done (Johnson & Christensen, 2004; Krejcie & Morgan, 1970). In the second semester of 2012 with a population size of 1 267, 297 responses would have sufficed (Johnson & Christensen, 2004; Krejcie & Morgan, 1970). In actual fact, during the first semester 475 respondents satisfied the criteria set to be included in the statistical analysis (see section 6.1.1) and in the second semester 532 respondents satisfied these criteria. In both cases the number of respondents included in the statistical analysis was well above the required numbers.

Bartlett, Kotrlik and Higgins (2001) recommend that to use multiple regression analysis in a study , the ratio of observations to independent variables should be between five and ten, with ten seen as the optimal value. The same criteria apply when doing factor analysis, with the additional criterion that factor analysis should not be done with less than 100 observations. Since seven independent variables were investigated, the number of responses for both semesters was sufficient to allow multiple regression analysis and factor analysis to be done.

Johnson and Christensen (2004) indicate several aspects to be taken into account with regard to sample size applicable to this study, – including the following

- A smaller sample size may be used for a homogeneous population, which is not the case for the COS1511 students.
- If the effect or relationship of an independent variable on a dependent variable is expected to be weak, a larger sample is required. Before the analysis was done, the effect of the independent variables on the dependent variable was unknown.
- More efficient random sampling methods need smaller samples. Self-selected sampling is not the most efficient random sampling method available.

Taking these considerations into account, as well as the response rates of the questionnaires administered in the first implementation cycle, the findings from the first implementation cycle will not be generalised, but should hold, with caution, for those students in the 2012 COS1511 population that met the criteria for inclusion in the statistical analysis.

The final marks (that is, the sum of the marks for the MCQs in Part A, the questions in Part B of the examination paper and the year mark) were used as dependent variable in the statistical analysis to determine how the biographical properties of the students, positive user experience, tracing and the extent and manner of tutorial use affected their marks. The final mark is represented by PM% in the statistical analysis.

6.3.2 Biographical detail and descriptive statistics

The biographical detail for the *first semester* 2012 respondents to the questionnaire is shown in Table Table D.1.17. The majority of the students were male (74%). Approximately half of the students were between 19 and 27 years of age (53%). Only 13% of respondents were full-time students who did not work at all. Seventy-four per cent of the students worked full-time and 45% worked in a field related to their degree. Note that this does not imply that their work involved programming, since COS1511 is offered to a number of different degrees and diplomas in various faculties. The remainder worked part-time. Matric was the highest qualification of most students (52%), while 20% had a national certificate and 21% a diploma. Six per cent had a degree and 2% a post-graduate degree.

Only 34% had English as their first language while 20% had Afrikaans as first language and the remainder another language. Since South-Africa has 11 official languages and Unisa is an international institution, all languages other than English and Afrikaans were grouped together. Forty-six per cent indicated that they passed Mathematics with a C symbol on Higher or Standard grade, while one per cent did not have Mathematics in matric. Fifty per cent indicated that they passed English with a C symbol on higher or standard grade. Note that there is a possibility that students may not have understood what a C symbol means, or the difference between higher and standard grade, since their responses did not always correspond to the information obtained from Unisa's student system.

Thirty-nine per cent had Computer Applications Technology, Information Technology or Computer Studies at school. Thirty-six per cent did some form of computer literacy course, 35% used a computer daily at work, 12% ascribed their computer-literacy to taking Computer Applications Technology, Information Technology or Computer Studies at school and the remainder were self-taught.

The biographical detail for the *second semester* respondents to the questionnaire is shown in Table D.1.18. Male students formed the largest portion of this cohort (70%). The students were fairly young, with 67% of them between 19 and 27 years old. The majority were studying part-time (67%). Many of them were unemployed (26%), and nearly as many worked in an IT-related environment (25%). Sixteen per cent claimed to be full-time students. Most students had matric (64%), while 14% had a national certificate and 16% had a diploma. Very few students had a degree (4.51%) or postgraduate degree (1.69%). For 39% of the students English was their first language, while 17% had Afrikaans as first language and the remainder had another language as their first language.

Forty-five per cent of the students indicated that they had studied Computer Applications Technology, Information Technology or Computer Studies at school. Forty-three per cent of the respondents had been enrolled for COS1511 previously. This is an indication that they might have had problems mastering the module. Fifteen per cent had Computer Applications Technology, Information Technology or Computer Studies at school. Forty-two per cent did some form of computer literacy course, 22 % used a computer daily at work, 15% ascribed their computer-literacy to taking Computer Applications Technology, Information Technology or Computer Studies at school and 20% were self-taught.

6.3.3 Factors that could influence the a student's final mark (PM%)

To answer the second and third research questions, questionnaire items were selected as probable explanatory effects on students' final marks. The second research question enquired whether the tutorial to teach tracing assisted students in acquiring programming skills so that it is noticeable in their final mark. Question 13 asked students to indicate whether they used the tutorial or not. This was included in the statistical analysis as one of the factors that could possibly influence a student's final mark. The third research question investigated how students' biographical properties, their positive user experience, tracing and the manner of their use of the tutorial affected their ability to acquire programming skills, by investigating the effect of these on their examination marks. These were all factors or independent variables that could also influence the dependent variable, that is, the final mark for each student. Before describing the models of the relationships between the dependent and independent variables, these factors are discussed.

6.3.3.1 English and Mathematics marks

Since a good mark in Mathematics can possibly contribute to better performance in programming (AlgoViz Portal; Bergin & Reilly, 2006; Byrne & Lyons, 2001; Chmura, 1998; Pillay & Jugoo, 2005; White & Sivitanides, 2003; Wilson & Shrock, 2001) and students whose first language differs from the teaching language, may perform more poorly (Carter et al., 2007; Gous & Roberts, 2014; Pillay & Jugoo, 2005), it was expected that both the Mathematics and English marks of student might have influenced their performance.

The questionnaire for the first semester included questions on students' matric (Grade 12) results for Mathematics and English (questions 6 and 7). However, the high school syllabi for Mathematics and English have been revised several times during the past few years with resulting name changes. See Table 6.5 for the different types of Mathematics and English students can offer as a Grade 12 subjects at Unisa. Therefore, it was decided to use the respondents' Grade 12 English and Mathematics results as obtained from the Unisa student system, to include in the profile score. A mark of 60% or more was used as the cut-off level for both English and Mathematics, regardless of which type of Mathematics or English the student had in Grade 12.

Table 6.5 Types of English and Mathematics accepted as Grade 12 (Matric) subjects at Unisa

English	Mathematics
Subject	**Subject**
English - First Language	Additional Mathematics
English -Second Language	Commercial Mathematics
English	Mathematics HG 50 (Dept)
English - Home Language	Mathematics
	Mathematical Literacy
	Maths Third Paper

Figure 6.7 and Figure 6.8 show the frequency distributions for all respondents' marks in Mathematics for the first and second semesters in 2012. The mean percentage for Mathematics obtained by all respondents in the first semester was 51.52%, with a standard deviation of 14.49 and for the second semester the mean percentage was 51.62%, with a standard deviation of 15.57.

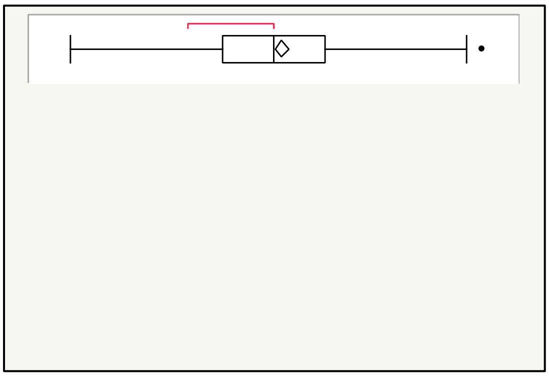


Figure 6.7 Distribution of Mathematics marks for 2012 semester 1 respondents

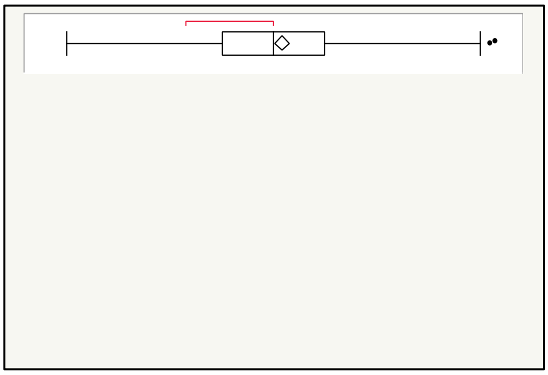


Figure 6.8 Distribution of Mathematics marks for 2012 semester 2 respondents

Figure 6.9 and Figure 6.10 show the frequency distributions for all respondents' marks in English obtained by first and second semester students. The mean percentage for English obtained by first semester students was 53.05%, with a standard deviation of 12.04; and for the second semester students it was 54.23%, with a standard deviation of 11.92. Supporting tables for both semesters are shown in Appendix D.1.5.

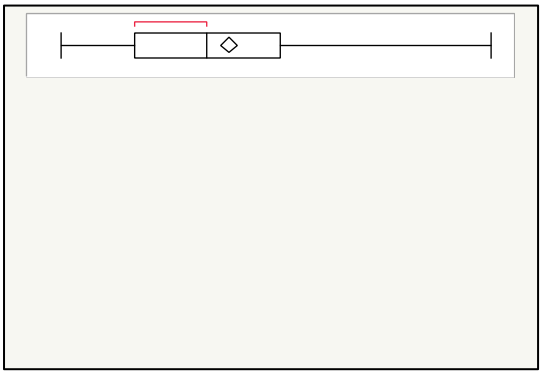


Figure 6.9 Distribution of English marks for 2012 semester 1 respondents

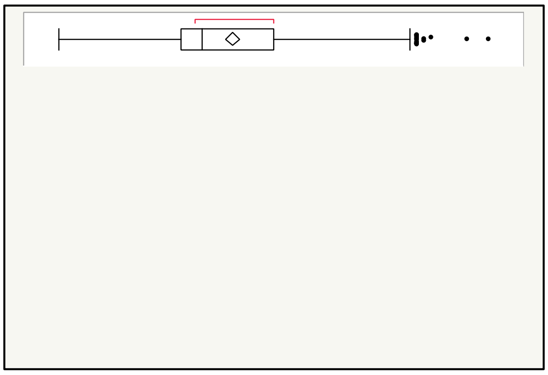


Figure 6.10 Distribution of English marks for 2012 semester 2 respondents

From the above statistics it is clear that a large portion of the respondents did not do well in Mathematics and English at school, and that the average mark for both Mathematics and English were mediocre. To investigate the influence of the Mathematics and English marks of respondents, these marks were included as part of their biographical profile score.

6.3.3.2 Profile score

The effect of biographical properties on COS1511 students' performance were included and accommodated in the quantitative analysis by calculating a single biographical score per student based on the biographical properties of –

- respondents' level of prior programming experience (recall that prior programing experience was identified as contributing to performance in introductory programming courses (Byrne & Lyons, 2001; Wilson & Shrock, 2001);
- their Grade 12 (matric) English level;
- their Grade 12 (matric) Mathematics level; and
- first-time COS1511 registration or not (question 11).

This score (referred to as 'the profile score' in the analysis) reflected a summative biographical effect of respondents.

The table of frequency distributions which follow serves to explain the profile score in more detail. Table 6.6 shows the frequency distributions for all respondents for both semesters in 2012.

Question 10 in the questionnaire (What experience do you have in ***programming***?) included the following options:

1. Computer Studies or Information Technology at school
2. Repeating COS1511
3. Currently enrolled for another programming module at Unisa
4. Did a programming course other than COS1511
5. Employed as a programmer

This was used to identify respondents' prior programming experience. Respondents who did not answer the question, who were repeating COS1511 (option 2) or were currently enrolled for another programming module at Unisa (option 3) were classified as having no programming experience and received a score of 0. Respondents who did Computer Studies or Information Technology at school (option 1) or did a programming course other than COS1511 (option 4) were seen as having some programming experience, and received a score of 1. Respondents who were employed as programmers (option 5) were seen as being experienced and received a score of 2. In the first semester all respondents completed question 10. In the second semester ten respondents did not complete question 10, and they were included with the group who were repeating COS1511. In the first semester 41% of respondents had no experience while 10% were experienced. In the second semester 56% had no experience, while 6% were experienced. In section 6.3.3.4 the unclassified responses to question 10 are discussed in more detail.

Table 6.6 Frequency distributions for questions used to calculate a profile score for respondents for both semesters in 2012

	Semester 1		**Semester 2**	
Q10 Programming experience?	**N**	**% of Total**	**N**	**% of Total**
No experience (0 - Repeating COS1511 or registered for another programming module simultaneously)	195	41.05%	293	56.13%
Moderate (1 - IT at school or completed other programming course)e	231	48.63%	196	37.55%
Experienced (2 - Employed as a programmer)	49	10.32%	33	6.32%
All	475	100.00%	522	100.00%
MATH >=60				
No	296	62.32%	343	64.47%
Yes	179	37.68%	189	35.53%
All	475	100.00%	532	100.00%
ENG >= 60				
No	281	59.16%	328	61.65%
Yes	194	40.84%	204	38.35%
All	475	100.00%	532	100.00%
Q11 FIRST time you have been registered for COS1511?				
No	133	28.00%	244	45.86%
Yes	342	72.00%	288	54.14%
All	475	100.00%	532	100.00%
Profile score				
0	62	13.05%	127	23.87%
1	87	18.32%	118	22.18%
2	116	24.42%	125	23.50%
3	122	25.68%	83	15.60%
4	81	17.05%	69	12.97%
5	7	1.47%	10	1.88%
All	475	100.00%	532	100.00%

Mathematics and English marks for respondents as extracted from the Unisa student system were used to distinguish between respondents who obtained less than 60% (0); or 60% or more. Only 38% of first semester respondents and 36% of second semester respondents obtained 60% or more in matric for Mathematics. Forty-one per cent of first semester respondents and 38% of second semester respondents obtained 60% or more for English.

A large percentage of respondents were repeating the module (28% of the first semester respondents and 46% of the second semester respondents). The majority of both first and second semester students obtained a profile score of between zero and two (56% and 70% respectively).

6.3.3.3 Positive user experience (questions 17 to 21)

Instead of investigating the effect of five sets of user experience response ratings on examination marks, a single set of response ratings – which represents a combined measure of respondents' user experience – was investigated for its effect on examination marks.

The questionnaire items investigated in questions 17 to 21 as listed in Tables 6.7 and 6.8 (their frequency distributions) were used to describe the joint construct of 'positive user experience of the

Drawing Variable Diagrams Tutorial usage'. Table 6.7 describes the joint construct of 'positive user experience of the Drawing Variable Diagrams Tutorial usage' for the first semester in 2012, while Table 6.8 describes it for the second semester.

Table 6.7 User experience response ratings representing positive user experience of the Drawing Variable Diagrams Tutorial usage for semester 1 2012 (all respondents)

	Not-Neutral		**Somewhat**		**Useful-very**		**All**	
	N	**% of Total**	**N**	**% of Total**	**N**	**% of Total**	**N**	**% of Total**
Q17 To what degree did the tutorial assist you to master tracing?	133	28.00%	93	19.58%	249	52.42%	475	100.00%
Q18 Did you find it interesting to use the tutorial?	89	18.74%	91	19.16%	295	62.11%	475	100.00%
Q19 Did you find it motivating to use the tutorial?	108	22.74%	78	16.42%	289	60.84%	475	100.00%
Q20 To what degree did you enjoy using the tutorial?	35	7.37%	148	31.16%	292	61.47%	475	100.00%
Q21 Did you find it irritating to use the tutorial? *	16	3.37%	49	10.32%	410	86.32%	475	100.00%

Legend: * - Question 21 was inverted because it was negative.

Table 6.8 User experience response ratings representing positive user experience of the Drawing Variable Diagrams Tutorial usage for semester 2 2012 (all respondents)

	Not-Neutral		**Somewhat**		**Useful-very**		**All**	
	N	**% of Total**	**N**	**% of Total**	**N**	**% of Total**	**N**	**% of Total**
Q17 To what degree did the tutorial assist you to master tracing?	143	26.98%	131	24.72%	256	48.30%	530	100.00%
Q18 Did you find it interesting to use the tutorial?	129	24.34%	101	19.06%	300	56.60%	530	100.00%
Q19 Did you find it motivating to use the tutorial?	125	23.58%	114	21.51%	291	54.91%	530	100.00%
Q20 To what degree did you enjoy using the tutorial?	45	8.49%	178	33.58%	307	57.92%	530	100.00%
Q21 Did you find it irritating to use the tutorial? *	448	84.69%	55	10.40%	26	4.91 %	529	100.00%

Legend: * - Question 21 was inverted because it was negative.

The item analysis for positive user experience for both semesters showed Cronbach's coefficient alphas[15] of above 0.82, confirming the reliability of the questions (Terre Blanche et al., 2006), as can be seen in Table 6.9. Supporting tables are shown in Appendix D.1.6.

Table 6.9 Cronbach's coefficient alphas for positive user experience for both semesters in 2012

Semester	**Cronbach's coefficient alpha**
Semester 1 2012	0.8824
Semester 2 2012	0.8323

[15] Cronbach's coefficient alpha is the most common estimate of internal consistency, which is the degree to which each item in a scale correlates with each other. An alpha value of 0.75 is considered to indicate reliable internal consistency (Terre Blanche et al., 2006).

Since internal consistency reliability was established a ‘positive user experience’ score could be calculated to represent the five separate questionnaire items in evaluating whether user experience affects examination marks (in conjunction with the other effects already mentioned). The frequency distributions of the calculated ‘positive user experience’ scores are also presented in Tables 6.7 and 6.8. Note that the rating scale classes have been condensed in both tables to three rating categories. Question 21 (Did you find it irritating to use the tutorial?) was negative and therefore inverted.

Most students claimed that the tutorial assisted them to master tracing. Fifty-two per cent of first semester respondents found it useful or very useful and 20% found it somewhat useful. In semester 2, 48% found it useful or very useful and 25% found it somewhat useful. Most respondents found the tutorial fairly or very interesting to use (62% of first semester respondents, and 57% of second semester respondents). Likewise, most respondents found it motivating (61% in semester 1 and 55% in semester 2). Most respondents also enjoyed using the tutorial (61% in semester 1 and 58% in semester 2). Very few students found the tutorial irritating (3% in semester 1 and 5% in semester 2).

The positive user experience score for a student was calculated as the average of the ratings of all five questions, which can range from 0 to 5. A score of 4 on the user experience for example, indicates that a student answered four of the questions with a rating of ‘useful’ or ‘very useful’. This reflects a very positive user experience. The mean positive user experience score for students in the first semester, came to 3.75 when calculated, while for the second semester it came to 3.68. These mean scores indicate that respondents had a positive user experience of the tutorial. The reason for the last statement is that since the individual user experience scores were calculated for each individual as the mean rating of each individual’s ratings of the five questions in question, the same rating scale values apply to the user experience scores, namely ‘1’ indicating ‘not at all’; ‘2’ indicating a ‘neutral’ feeling; ‘3’ indicating ‘somewhat of value’; ‘4’ indicating ‘fairly useful’ and ‘5’ indicating ‘very useful’. Supporting tables are shown in Appendix D.1.6.

Note that some students did not use the tutorial for a long time (less than 1 hour), or did not need the tutorial, but might have perused it, and therefore may have indicated their impression, even if they had not used it. The user experience was therefore calculated for all respondents.

Figure 6.11 and Figure 6.12 show the frequency distributions for the user experience of all respondents for the first and second semesters in 2012 respectively.

In the next section students’ prior experience of programming, their use of tracing and the time they spent using the tutorial are discussed.

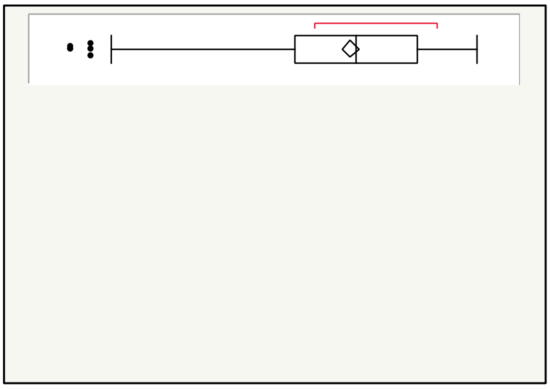


Figure 6.11 Distribution of Positive user experiences for 2012 semester 1 respondents

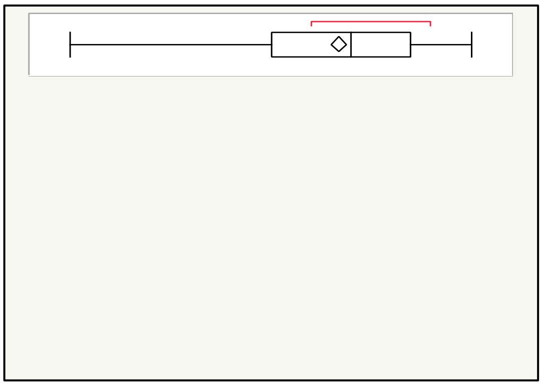


Figure 6.12 Distribution of Positive user experiences for 2012 semester 2 respondents

6.3.3.4 Students' prior experience of programming, use of tracing and time spent using the tutorial

Table 6.10 shows the frequency distribution of questionnaire items for the both semesters in 2012 for all respondents on –

- programming experience (question 10);
- drawing variable diagrams before enrolling for COS1511 (question 12);
- using the tutorial while working through the study guide (question 13);
- drawing variable diagrams to understand programs in the Study Guide (question 14);
- drawing variable diagrams to understand to debug (question 15); and
- time spent using the tutorial (question 16).

Note that question 11 (prior registration for COS1511 or not) was included in the profile score.

As mentioned before, the responses to question 10 were collapsed into three for the purpose of the profile score – no experience, moderate and experienced. Here the unclassified responses are reported. Note that the number of responses to option 2 in question 10 (repeating COS1511), differ from the number in question 11, where there were only two options (first time registered for COS1511 or not). When respondents reported their own programming experience, 21% of first semester respondents and 42% of second semester respondents indicated that their programming experience are limited to repeating COS1511. In the first semester 20% of respondents were enrolled for another programming module, while 14% of second semester respondents were enrolled for another programming module.

Twenty-four per cent of first semester respondents and 16% of second semester respondents had completed another programming course. Approximately a quarter (25% of first semester respondents and 22% of second semester respondents) had Computer Applications or Information Technology at school, while 10% of first semester respondents and 6% of second semester respondents were employed as programmers.

Table 6.10 Frequency distribution of questionnaire items for students' prior experience of programming and use of tracing for semesters in 2012 (all respondents)

	Semester 1		**Semester 1**	
Q10 What experience do you have in programming?	**N**	**% of Total**	**N**	**% of Total**
IT at school	119	25.05%	115	22.03%
Repeating COS1511	100	21.05%	219	41.95%
Currently enrolled for another programming module	95	20.00%	74	14.18%
Completed programming course other than COS1511	112	23.58%	81	15.52%
Employed as programmer	49	10.32%	33	6.32%
All	475	100.00%	522	100.00%
Q12 Have you drawn variable diagrams before enrolling for COS1511?				
Yes	110	23.16%	132	24.81%
No	365	76.84%	400	75.19%
All	475	100.00%	532	100.00%
Q13 Do you use the tutorial for this module while working through the study guide?				
Yes	396	83.37%	438	82.33%
No	79	16.63%	94	17.67%
All	475	100.00%	532	100.00%
Q14 Do you draw your own variable diagrams to help you to understand programs in the study guide?				
Yes	309	65.05%	383	71.99%
No	166	34.95%	149	28.01%
All	475	100.00%	532	100.00%
Q15 Do you draw your own variable diagrams to debug your programs?				
Yes	235	49.47%	281	52.82%
No	240	50.53%	251	47.18%
All	475	100.00%	532	100.00%
Q16 Up to now, how much time in total, have you spent using the tutorial?				
Less than 1 hour	58	12.21%	91	17.13%
1-3 hours	130	27.37%	193	36.36%
4-6 hours	85	17.89%	91	17.13%
7 -8 hours	46	9.68%	46	8.66%
More than 8 hours	156	32.84%	110	20.72%
All	475	100.00%	531	100.00%

The majority of respondents had never drawn variable diagrams before (77% in the first semester and 75% in the second semester). Most of the respondents indicated that they used the tutorial while working through the Study Guide[16] (83% in the first semester and 82% in the second semester). The majority of respondents claimed to draw variable diagrams to assist them in understanding programs in the Study Guide (65% in the first semester and 72% in the second semester). Approximately half of the respondents drew variable diagrams to help them debug their programs (49% in the first semester and 53% in the second semester).

By the time respondents completed the questionnaire (when submitting assignment 1) they should have studied lessons 1 to 14 in the Study Guide. These lessons included eleven activities in the

[16] COS1511 students use a Study Guide instead of a prescribed text book.

Drawing Variable Diagrams Tutorial. In the first semester, 12%, and in the second semester 17% of respondents spent less than one hour using the tutorial, that is, they probably only perused the tutorial. Twenty-seven per cent of first semester respondents and 36% of second semester respondents spent one to three hours using the tutorial. Eighteen per cent of first semester respondents and 17% of second semester respondents spent between four and six hours using the tutorial, while the remainder spent seven or more hours using the tutorial.

In the next section the model for relationships between the final mark (PM%) and factors that could possibly affect it, is discussed.

6.3.4 Modelling the relationships between the final mark and factors that could possibly affect it

The relationships between the final mark (PM%) and factors that could possibly influence it were modelled on all the data. Set against the factors discussed in sections 6.3.3.1 to 6.3.3.4, the following variables and composite variables were investigated for the statistical significance of their combined effect on final marks (PM% in the model):

- Biographical profile of respondents as summarized in the set of profile scores;
- User experience as measured by the positive user experience scores;
- Prior use of variable diagrams (question 12);
- Using the tutorial or not (question 13);
- Drawing variable diagram to understand programs in the Study Guide (question 14);
- Drawing variable diagrams to debug (question 15); and
- Time spent using the tutorial (question 16).

Multiple linear regression was used to fit the model for relationships between the final mark (PM%) and factors that could possibly influence it, for both semesters. The fit of the model for the first semester in 2012 is described in section 6.3.4.1 and the fit of the model for the second semester in section 6.3.4.2. These models were also fitted with decision trees in section 6.3.4.3. For further clarification, the relationships between time spent in using the tutorial and the final marks, as well as between programming experience and the final marks, were also modelled with ANOVAs in sections 6.3.4.4 and 6.3.4.5.

6.3.4.1 First semester 2012 model on all the data for relationships between the final mark (PM%) and the factors that could possibly influence it

Multiple linear regression was used to fit the full model on all the data. The full model for the first semester in 2012 is statistically significant with a p-value of less than 0.01, indicating a level of 99% of confidence ($F_{14,474} \approx 25.9437$; $p < 0.0001$).

The effect tests for the full model for the first semester in Table 6.11, show that the profile score ($p < 0.0001$), positive user experience ($p = 0.0241$), and having drawn variable diagrams before enrolling for COS1511 ($p = 0.0007$) are significant predictors of examination marks. The independent variables in the full model explain 42.42% of the variance in final marks, indicating a reasonable fit.

Table 6.11 Effect tests for the full model semester 1 2012

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Profile score	5	5	115431.81	54.0111	<.0001*
Positive User Experience	1	1	2187.97	5.1188	0.0241*
Q12 Own variable diagrams BEFORE	1	1	5033.14	11.7752	0.0007*
Q13 Used the tutorial	1	1	112.68	0.2636	0.6079
Q14 Own variable diagrams STUDY	1	1	528.69	1.2369	0.2667
Q15 Own variable diagrams DEBUG	1	1	886.86	2.0748	0.1504
Q16 Time spent tutorial	4	4	2391.58	1.3988	0.2333

To produce the final model, stepwise multiple linear regression was done to find the significant independent variables in the full model on all the data. The final model in the first semester is statistically significant with a p-value of less than 0.01, indicating a level of 99% of confidence ($F_{8,474} \approx 43.9813$; $p < 0.0001$).

The effect tests for the final model in the first semester in Table 6.12 confirm that the profile score ($p < 0.0001$), positive user experience ($p = 0.0077$), and having drawn variable diagrams before enrolling for COS1511 ($p = 0.0002$) are significant predictors of final marks. The independent variables in the final model explain 42.04% of the variance in final marks, indicating a reasonable fit, similar to that of the full model. Supporting tables and graphs are shown in Appendix D.1.7.

Table 6.12 Effect tests for the final model semester 1 2012

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Profile score	5	5	124281.15	57.7731	<.0001*
Positive User Experience	1	1	3083.23	7.1663	0.0077*
Q12 Own variable diagrams BEFORE	1	1	6011.29	13.9720	0.0002*

The prediction profiler for the final model for the first semester in Figure 6.13 shows clearly that a higher profile score had the biggest effect on a student's final mark for COS1511. Having drawn variable diagrams before enrolling for COS1511 (Q12) had a small positive effect on a student's final mark. Drawing their own variable diagrams to help them to understand programs in the Study Guide (Q14) had virtually no effect. A higher positive user experience is associated with a slightly lower final mark.

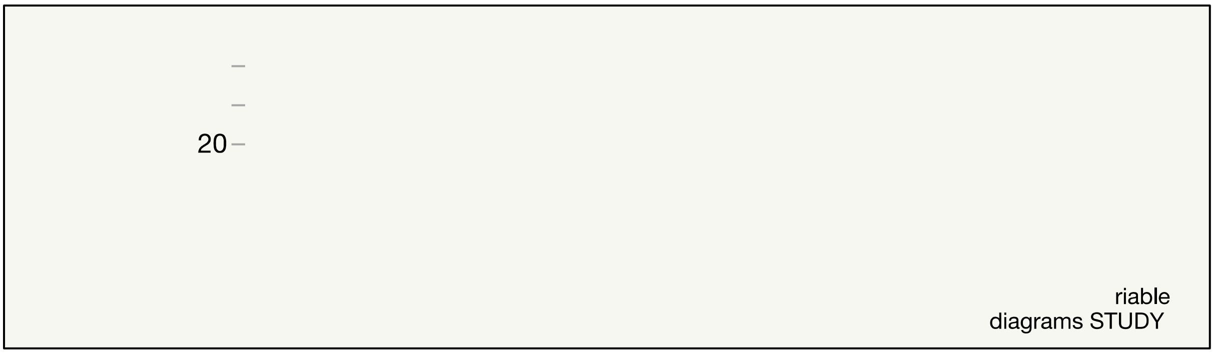


Figure 6.13 Prediction profiler for the final model semester1 2012

6.3.4.2 Second semester 2012 model on all the data for relationships between the final mark (PM%) and the factors that could possibly influence it

Multiple linear regression was also used to fit the full model for the second semester on all the data. The full model for the second semester is statistically significant with a p-value of less than 0.01, indicating a level of 99% of confidence ($F_{12,529} \approx 23.2767$; $p < 0.0001$).

The effect tests for the full model in the second semester in Table 6.13 show that the profile score ($p < 0.0001$), having drawn variable diagrams before enrolling for COS1511 ($p = 0.0397$), using the tutorial while working through the Study Guide ($p = 0.0047$), and drawing variable diagrams to debug programs ($p = 0.0371$) are significant predictors of final marks. The independent variables in the full model explain 33.56% of the variance in final marks, indicating a reasonable fit.

Table 6.13 Effect tests for the full model semester 2 2012

Source	**Nparm**	**DF**	**Sum of Squares**	**F Ratio**	**Prob > F**
Profile score	5	5	77498.388	41.9250	<.0001*
Positive user experience	1	1	318.705	0.8621	0.3536
Q12 Own variable diagrams BEFORE	1	1	1571.241	4.2500	0.0397*
Q13 Used the tutorial	1	1	2976.615	8.0514	0.0047*
Q14 Own variable diagrams STUDY	1	1	215.864	0.5839	0.4451
Q15 Own diagrams DEBUG	1	1	1614.158	4.3661	0.0371*
Q16 Time spent tutorial	2	2	525.564	0.7108	0.4917

To produce the final model, stepwise multiple linear regression was done to find the significant independent variables in the full model on all the data. The final model in the second semester is statistically significant with a p-value of less than 0.01, indicating a level of 99% of confidence ($F_{7,531} \approx 39.36722$; $p < 0.0001$).

The effect tests for the final model in the second semester in Table 6.14 confirm that the profile score ($p < 0.0001$), having drawn variable diagrams before enrolling for COS1511 ($p = 0.0206$), and using the tutorial while working through the study guide are significant predictors of final marks. The independent variables in the final model for the second semester explain 33.63% of the variance in final marks, indicating a reasonable fit, similar to that of the full model. Supporting tables and graphs are shown in Appendix D.1.8.

Table 6.14 Effect tests for the final model semester 2 2012

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Profile score	5	5	83587.184	45.1314	<.0001*
Q12 Own variable diagrams BEFORE	1	1	1996.715	5.3905	0.0206*
Q13 Used the tutorial	1	1	3819.469	10.3113	0.0014*

The prediction profiler for the final model for the second semester shown in Figure 6.14 again shows clearly that a higher profile score had the most effect on a student's final mark for COS1511. As in the first semester, having drawn their own variable diagrams before enrolling for COS1511 had a small positive effect on a student's final mark. Using the tutorial while working through the Study Guide had a small negative effect on a student's final mark.

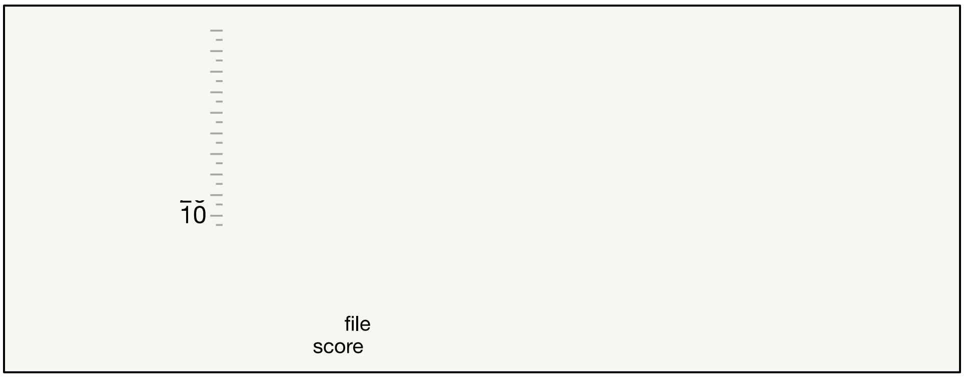


Figure 6.14 Prediction profiler for the final model semester 2 2012

6.3.4.3 Modelling with decision trees

Another fit with decision trees was also done for both semesters. The decision tree for the first semester in 2012 depicted in Figure 6.15 shows the effect of the two dominant factors in the model, that is, the profile score and having drawn variable diagrams before. It shows that 76% of students with a lower profile score (0 or 1) fail the module, while 78% of students with a profile score of 2, 3 or 4, pass the module. Ninety-six per cent of students with a profile score of 4 or 5 pass the module. Sixty-four per cent of the students with a profile score of 3 pass the module, and if they had drawn their own variable diagrams before, 81% pass the module. Fifty-nine per cent of students who have a profile score of 3, and have not drawn their own variable diagrams before, pass the module.

The decision tree for the second semester in Figure 6.16 shows the effect of the two dominant factors in the model, that is, the profile score and using the tutorial while working through the Study Guide. It shows that 81% of students with a lower profile score (0, 1 or 2) failed the module, while 67% of students with a profile score of 3, 4 or 5 passed the module. Eighty-seven per cent of students with a profile score of 3, 4 or 5, who did not use the tutorial, passed the module. Fifty-nine per cent of students with a profile score of 3, 4 or 5, who used the tutorial, passed the module. Fifty-three per cent of the students with a profile score of 3, who used the tutorial, failed. Seventy-three per cent of students who had a profile score of 4 or 5, who used the tutorial, passed the module.

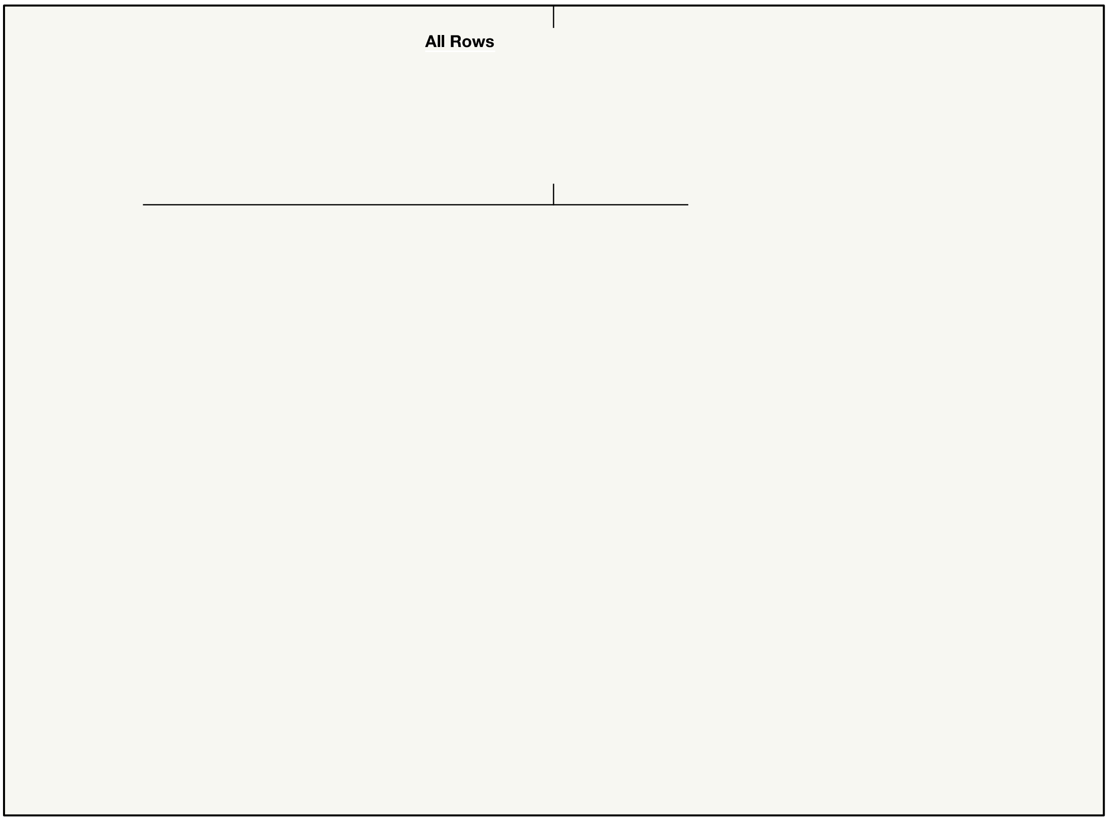


Figure 6.15 Decision tree: Effect of profile score and tracing experience of the final model for semester 1 2012

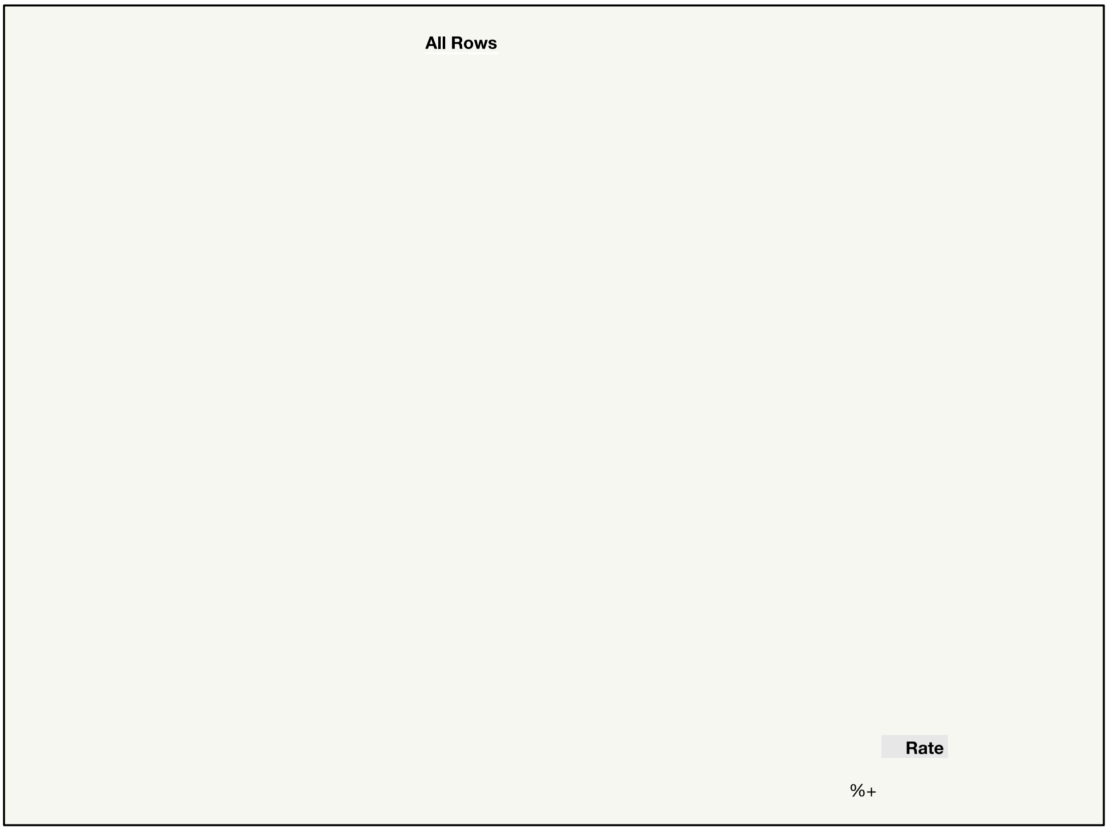


Figure 6.16 Decision tree: Effect of the profile score and using the tutorial while working through the Study Guide of the final model for semester 2 2012

6.3.4.4 Relationship between time spent using tutorial and PM%

Research indicates conflicting results about more time spent using visualizations (Hundhausen et al., 2002; Saraiya et al., 2004). Due to the difference in students' backgrounds and the qualifications they were registered for, it was very difficult to judge how much time an average student would spend using the tutorial to study the relevant activities, and also how much time the average student would need to benefit from using the tutorial. Therefore, the relationship between time spent using the tutorial and the final marks were investigated. A one-way ANOVA was conducted to examine whether there were significant differences between respondents' final mark (PM%) in relation to the time they spent using the tutorial for both semesters in 2012. The results revealed statistically significant differences between the time spent using the tutorial in the first semester ($F_{4,474} \approx 7.2883$; $p < 0.0001$) at a 99% level of confidence, as well as in the second semester ($F_{4,530} \approx 4.8116$; $p < 0.0008$) at a 92% level of confidence. Supporting tables for both semesters are shown in Appendix D.1.9.

Post-hoc Tukey-Kramer's t-tests revealed that there is a significant difference between spending less than one hour (M = 51.483626), and spending any number of hours between one and eight hours using the tutorial in the first semester (see Table 6.15 with the connecting letters report). For the second semester, post-hoc Tukey-Kramer's t-tests also revealed that there is a significant difference between spending less than one hour (M = 51.483626), or more than eight hours (M = 42.621182) using the tutorial, and spending any number of hours between one and eight hours using the tutorial (see Table 6.16 with the connecting letters report). Note that in the second semester spending more than eight hours was a borderline case which could be grouped with both spending less than one hour using the tutorial or spending any time using the tutorial. There were no other significant differences between time spent using the tutorial in either semesters. Respondents who used the tutorial for less than one hour, did better than those who used it for longer, no matter how much time they spent using the tutorial. Figures 6.17 and 6.18 illustrate the differences between the time spent using the tutorial in relation to the final marks. In both figures it is clear that those respondents who spent less than one hour using the tutorial, achieved higher marks than those who used the tutorial, no matter how much

Table 6.15 Connecting letters report: Relationship between time spent using tutorial and PM% semester 1 2012

Level			Mean
< 1 hour	A		64.310517
7-8 hours		B	49.214565
4-6 hours		B	46.653765
8+ hours		B	45.124487
1-3 hours		B	42.628231

(Levels not connected by the same letters are significantly different)

Table 6.16 Connecting letters report: Relationship between time spent using tutorial and PM% semester 2 2012

Level			Mean
< 1 hour	A		51.483626
8+ hours	A	B	42.621182
4-6 hours		B	40.378901
1-3 hours		B	40.230207
7-8 hours		B	36.364348

(Levels not connected by the same letters are significantly different)

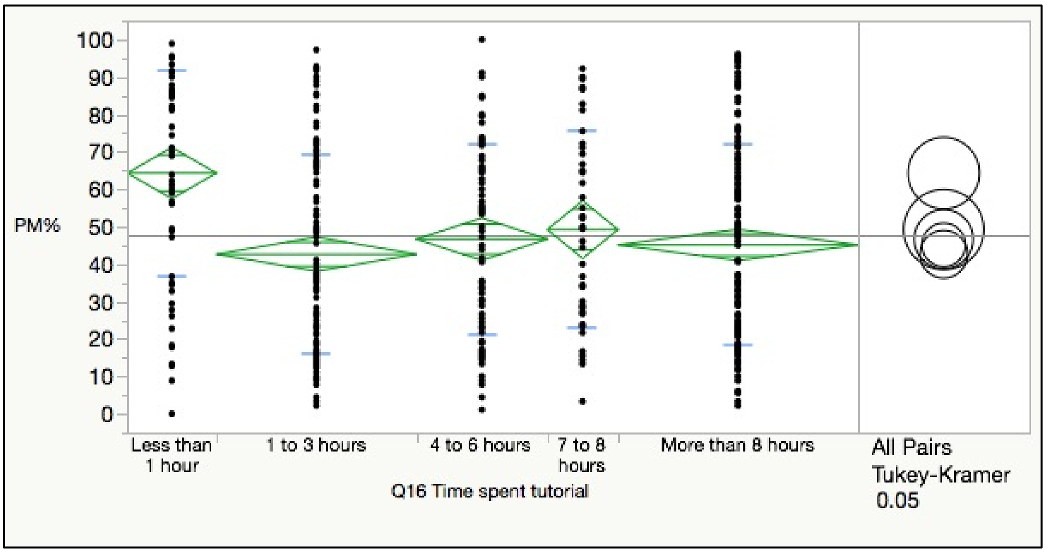


Figure 6.17 Visual comparison of group means illustrating differences between time spent using the tutorial in relation to PM% semester 1 2012

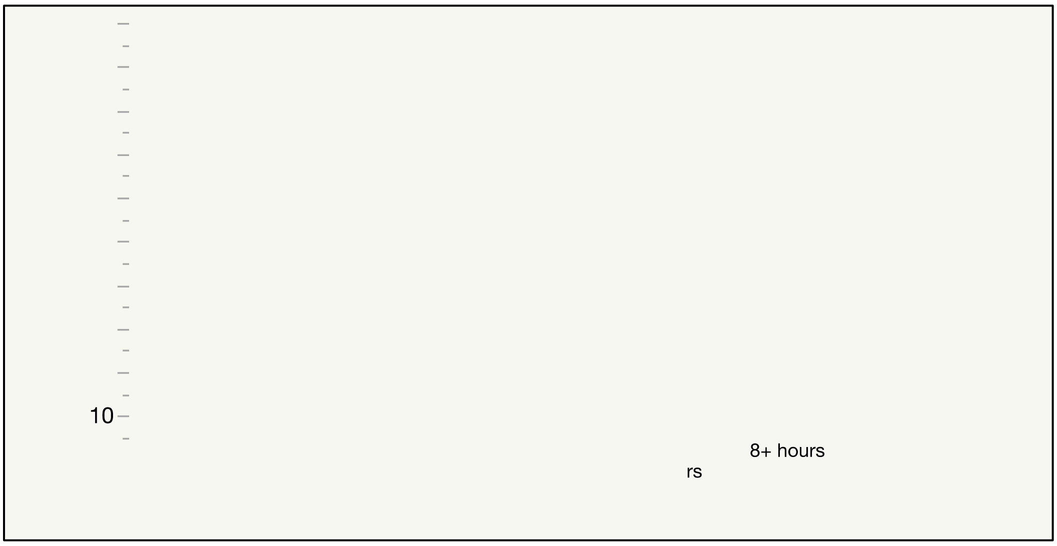


Figure 6.18 Visual comparison of group means illustrating differences between time spent using the tutorial in relation to PM% semester 2 2012

time they spent using it. The comparison circles on the right indicate the level of difference between pairs of group means. The intersections of each pair of group means indicate whether the group means are significantly different or not. Circles for means that are significantly different either do not intersect, or intersect slightly, while the means of circles that are nested are not significantly different.

6.3.4.5 Relationship between programming experience (Q10) and PM%

Programming experience was included as one of the components of the profile score, in a collapsed form, classified as no experience, moderate experience and experienced. To further investigate the extent of the effect of programming experience, a one-way ANOVA was conducted to examine whether there were significant differences between respondents' final mark (PM%) in relation to their programming experience for both semesters in 2012. The results revealed statistically significant differences between the programming experience in the first semester ($F_{4,474} \approx 33.4222$; $p < 0.0001$) at a 99% level of confidence, as well as in the second semester ($F_{4,521} \approx 33.9810$; $p < 0.0001$), also at a 99% level of confidence. Post-hoc Tukey-Kramer's t-tests revealed that in the first semester there is a significant difference between being employed as a programmer (M = 69.886939) or having completed a programming course other than COS1511 (M = 59.210625); having done Computer Studies or Information Technology at school (M = 49.262185); and repeating COS1511 (M = 36.995000) or being currently enrolled for another programming module at Unisa (M = 30.766211) (see Table 6.17 with the connecting letters report).

For the second semester, post-hoc Tukey-Kramer's t-tests also revealed that there is a significant difference between being employed as a programmer (M = 71.145152); having completed a programming course other than COS1511 (M =50.548272) or having done Computer Studies or Information technology at school (M = 48.806870); and repeating COS1511 (M = 35.329772) or being currently enrolled for another programming module at Unisa (M = 29.752432) (see Table 6.18 with the connecting letters report). There were no other significant differences between programming experiences in either semester. Supporting tables for both semesters are shown Appendix D.1.10.

Table 6.17 Connecting letters report: Relationship between programming experience and PM% semester 1 2012

Level				Mean
Employed as a programmer	A			69.886939
Did a programming course other than COS1511	A			59.210625
Computer Studies or Information Technology at school		B		49.262185
Repeating COS1511			C	36.995000
Currently enrolled for another programming module at Unisa			C	30.766211

(Levels not connected by the same letters are significantly different)

Table 6.18 Connecting letters report: Relationship between programming experience and PM% semester 2 2012

Level				Mean
Employed as programmer	A			71.145152
Did programming course other than COS1511		B		50.548272
Computer Studies or Information Technology at school		B		48.806870
Repeating COS1511			C	35.329772
Currently enrolled other module at UNISA			C	29.752432

(Levels not connected by the same letters are significantly different

Figures 6.19 and 6.20 illustrate the differences between programming experience in relation to the final marks. Respondents who were employed as programmers obtained the best marks, while respondents who were repeating COS1511 or were enrolled simultaneously for another programming module achieved the lowest marks. Respondents who have completed another programming course obtained higher marks than those who did Computer Studies or Information Technology at school.

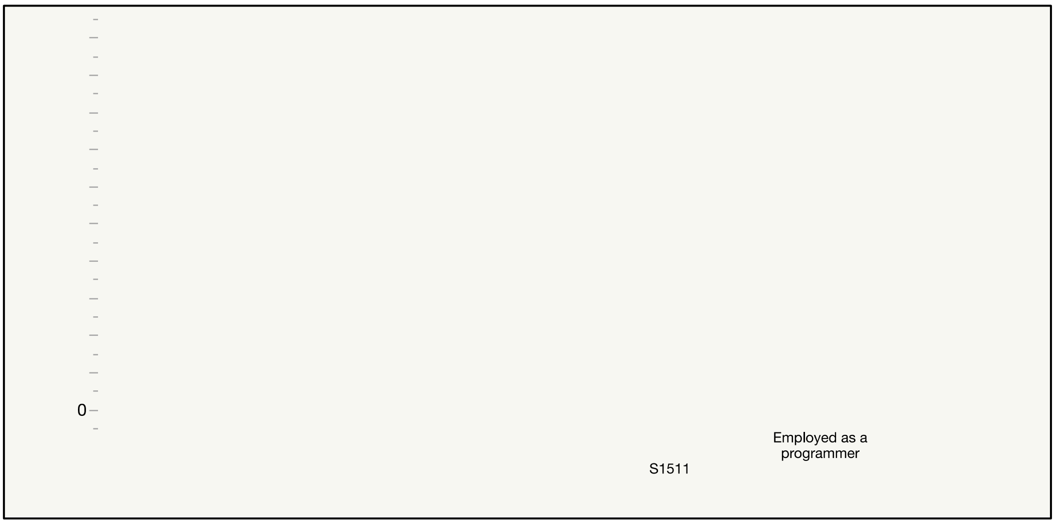


Figure 6.19 Visual comparison of group means illustrating the differences in programming experience in relation to PM% semester 1 2012.

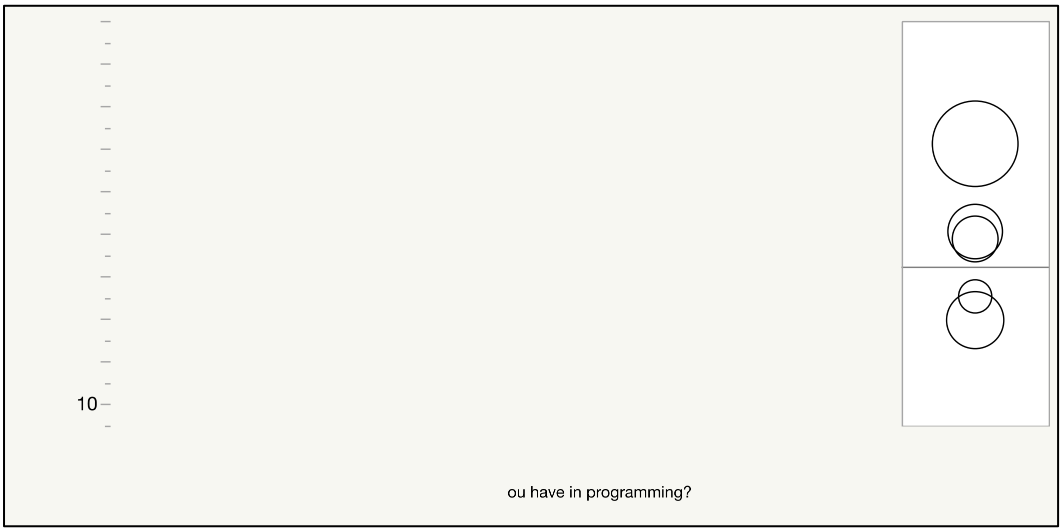


Figure 6.20 Visual comparison of group means illustrating differences in programming experience in relation to PM% semester 2 2012

From the above presentation, it transpired that the results from modelling the relationships between the final marks of students and factors that could possibly affect it, can be summarised as follows:

- The prediction profilers for the full model for both semesters in 2012 in Figures 6.15 and 6.16 show clearly that a higher profile score had the highest effect on a student's final mark for COS1511. Having drawn variable diagrams before enrolling for COS1511 also had a small positive effect on a student's final mark in both semesters. Students with a positive user experience in semester 1 actually achieved lower final marks than those who did not do so, as did students who used the tutorial in semester 2. Drawing their own variable diagrams to help them to understand programs in the Study Guide in semester 1 had virtually no effect on a student's final mark.

- The modelling with decision trees, confirms that the profile score had the highest effect on a student's final mark. It shows clearly that the majority of students with a profile score from 0 to 2 fail (76% in semester 1 and 81% in semester 2). Students with a profile score from 3 to 5, have a much better chance to pass the module, as from these students, only 22% in the first semester and 33% in the second semester failed the module. Due to the way scores were allocated for programming experience, a student could only obtain a profile score of 5, if he or she was employed as a programmer. A profile score of 4 could indicate a moderate level of programming experience that is, having completed another programming course or having had Computer Studies or Information Technology at school. In the first semester only 3% of students with a profile score of 4 or 5 failed the module, while 36% of those with a profile score of 3 failed. However, 81% of students in the first semester who had a profile score of 3, and had drawn variable diagrams before, which indicates having some programming experience, passed the module. Fifty-nine per cent of those who had a profile score of 3 but had not drawn variable diagrams before passed. This indicates that previous programming experience was an important factor in students' final marks.
- For the second semester the decision tree for profile scores from 3 to 5, split at using the tutorial or not. Eight-seven per cent of students who did not use the tutorial, most of whom probably had some programming experience, passed the module. From those who did use the tutorial, 47% of students with a profile score of 3, passed; while 74% of students with a profile score of 4 or 5 passed. Once again this confirms the role of previous programming experience in a student's final mark. It also shows that using the tutorial did not assist students in passing the module.
- The ANOVA models for both semesters discussed in in 6.3.4.5 confirm that programming experience was one of the key factors in passing the module. Similarly, the ANOVA models discussed in section 6.3.3.4 confirm that students who did not use the tutorial, probably because they did not need it due to having prior programming experience, achieved better final marks than those who used it. It seems as if using the tutorial did not benefit the students at all, no matter how much time they spent using it.

In the next section the qualitative investigation, where participants' use of the tutorial was observed, is discussed. Their feedback on how they experienced using the tutorial is also covered as part of the qualitative investigation.

6.4 Direct live observation and eye tracking in the HCI laboratory

Self-selecting sampling was used to recruit volunteers for observation and eye tracking while using the tutorial in the HCI laboratory at Unisa. An e-mail invitation to partake in the usability study was sent to all students registered for COS1511 who lived in the vicinity of Pretoria (see Appendix C.1).

They were told that the sessions would last approximately one to one-and-a-half hours. No incentive for taking part was offered as Unisa does not allow this. The purpose of the eye tracking sessions was to see how students would use the tutorial at home, and therefore participants were not told explicitly that they should read the instructions.

In the first implementation cycle the observations in the HCI laboratory were done during the fourth and fifth week of the second semester in 2012. Volunteers were requested to work through the first eleven lessons in the Study Guide before their eye tracking sessions, following the study plan for the module. This would have introduced them to their first C++ program, integers, variables, assignment statements, declaring variables, input and output statements, mathematical operators, floating point numbers, string and character variables, `if` statements, `while` loops, debugging and Boolean values, as well as drawing variable diagrams for these statements.

This discussion of the direct live observation and eye tracking in the HCI laboratory during this research, is continued by focusing on the procedure in the laboratory; the participants, analysis of gaze replays; and analysis of the questionnaire completed after eye tracking.

6.4.1 Procedure in HCI laboratory

Students were observed one at time. Once a participant had signed the informed consent form (see Appendix C.2), it was explained to him/her that the observation was intended to determine how students would use the Drawing Variable Diagrams Tutorial on their own at home. The participant was given the Task List in Appendix C and asked to draw variable diagrams for the first program in the Task List on paper. Table 6.19 describes the six activities participants had to work through during the observation.

Table 6.19 Description of activities worked through during observations in the HCI laboratory

Activity number in Drawing Variable Diagrams Tutorial	**Concept or construct animated in Drawing Variable Diagrams tutorial**
3.a.i	Shows how a declaration statement such as `int a;` reserves memory space.
4.a.ii	Demonstrates tracing and using variable diagrams for the assignment statement.
4.b	Demonstrates and trace a program line by line and use variable diagrams to show tracing of declaration statements and how the values of variables change with assignment statements.
5.a	Demonstrates line by line tracing of a program to illustrate arithmetic operators.
8.a.iii	Demonstrate tracing a simple `if else` statement.
9.a.v	Demonstrates tracing a `while` loop that prints values from 10 to 20.

After working through activities 3.a.i (reserving memory space for declarations), 4.a.ii (tracing assignment statements) and 4.b (tracing a program with declarations and assignment statements line by line) participants had to do the exercise at the end of activity 4.b. This required them to draw their own variable diagrams on paper with a different initial value for the program in activity 4.b. Thereafter participants had to work through activities 5.a (tracing a program with arithmetic operators), 8.a.iii (tracing a simple `if else` statement) and 9.a.v (tracing a `while` loop). Then they had to draw their own variable diagrams on paper for the second program on the Task List as a retrospective comprehension test. The second program differed slightly from the first one, but used the same programming constructs. Finally participants completed open-ended interview questions on paper (available in Appendix C).

Note that the observations were intended to investigate how students would *interact* with the tutorial when they encountered it for the first time, probably on their own and at home. This was an artificial situation. Due to time constraints students could not internalise and learn from the tutorial as they might have done in real life since the time constraints did not allow them to study the Study Guide in combination with the tutorial as intensively as they would have done in their own time. Therefore it is possible that they did not learn as much as they would have done under different circumstances.

6.4.2 Participants

Ten participants volunteered: two females and eight males. One of the ladies had vision impairment, and could not be eye tracked. As a result she was not included in the analysis. Table 6.20 provides a summary of the biographical information of the remaining participants. Feedback was obtained from the open-ended post-test questionnaire participants completed and background was acquired from the Unisa student system and/or conversations with the participants.

Table 6.20 Biographical information of participants observed in HCI laboratory

Participant	Age	Gender	First language	Qualification registered for	No of times registered for Cos1511	Drawn variable diagrams before	Used tutorial before	Exam results
1	33	female	Northern - Sotho	NDEEN*	no	no	yes	50%
2	29	male	Shona	BSc Informatics	yes	no	yes	61%
3	19	male	Afrikaans	BSc Computing	no	yes	no	64%
4	20	male	Swazi	BSc Computing	yes	yes	no	39%
5	20	male	Siswati/ English	NDINL**	no	yes	yes	20%
6	29	male	Venda	NDEEN	no	no	no	n/a
7	25	male	English	NDEEN	no	yes	no	64%
8	27	male	English	NDINL	no	no	yes	10%
9	28	male	XiTsonga	BSc Computing	no	no	yes	n/a

(Legend: *NDEEN – National Diploma in Electrical Engineering; **NDINL – National Diploma in Information Systems)

The ages of the participants varied from 19 to 33. The participants spoke eight different home languages. Two had not been registered for COS1511 before, while the others had all been registered before, but did not all progress to writing the examination. All claimed to be computer-literate.

Three participants were registered for the NDEEN, three for BSc Computing, two for the National Diploma in Information Systems and one for BSc Informatics. Five participants had never drawn variable diagrams before and four indicated that they had not used the Drawing Variable Diagrams Tutorial before the observations. Four participants passed the examination at the end of the semester, three failed and two did not write the examination.

6.4.3 Analysis of gaze replays

As indicated in section 4.3.5.3 gaze replays and observation were used to establish how participants experienced the usability of the Drawing Variable Diagrams Tutorial. The analysis is discussed based on issues identified during the observations and gaze replays. Four main issues were identified, namely, learning from the tutorial, the instructions on how to use the tutorial, navigation through the tutorial, and reading skills.

6.4.3.1 Learning from the tutorial

In order to learn from the tutorial (see section 5.5.1.2 for a description of a typical run), it was expected that students would firstly study the program code in the Program Box to form an idea of the purpose of the program, then read the highlighted program statement again and study the explanation in the Explanation Box to make sure they understand the statement. Thereafter they were expected to inspect the Memory Box to see how the variable diagrams for the statement are drawn (if any) and to look at the Console Window to inspect the output (if any) produced or to examine the input given to the program. To continue to the next statement in the program students should have clicked on the *Next* button, and to return to the previous statement, on the *Back* button.

Although this was a very artificial situation requiring participants to work through more than would typically be done during one session in their own time, participants did not seem to learn from working through the tutorial. This was evident in the fact that the variable diagrams drawn for the pre-test and retrospective comprehension tests by the three participants who did so (participants 1, 2 and 3), did not differ. Recall that the pre-test and retrospective comprehension tests were deliberately very similar, both using `while` loops with an `if` statement in the loop body; and that students were requested to work through the study guide up to lesson 11 before the observations in order to cover the study material presented in the activities they had to work through during the eye tracking and observation.

Six participants did not read the program code and explanations. They simply scanned it or only read part of it (participants 1, 3, 4, 6, 8, 9). Only three participants reconciled the four boxes in an activity as was expected (participants 2, 5 and 7). Despite using the tutorial as was expected, the (incorrect) variable diagrams drawn by participant 2 in the pre-test and retrospective comprehension tests did not differ, participant 5 did not draw variable diagrams, and the variable diagrams for the pre-test and retrospective comprehension test programs drawn by participant 7 were not correct, although he used the tutorial to assist him in drawing his own variable diagrams for activity 4.b, which he did correctly. The behaviour and variable diagrams drawn by the participants are briefly described below.

Participant 1 initially did not read the explanations or code before realising how to use the tutorial after frequently referring back to the instructions. She drew the variable diagrams for both the pre-test and the retrospective comprehension test before she worked through the tutorial, but rechecked them afterwards and requested the researcher to check whether she did it correctly. She made only one mistake – an incorrect line number.

Participant 2 never used the instructions, but nevertheless fairly quickly grasped how to use the tutorial. The gaze replays showed that he used the tutorial to help him understand the relationship between the program code and the resulting variable diagrams – he repeatedly compared the contents of the Memory box with the program code, the Console window and the Explanation box. He did not use line numbers when he drew variable diagrams, and did not realise that variables kept their values when a loop is executed – for each execution of the loop and the corresponding input value he drew the variable diagrams as if the variables had not been assigned any values yet. He did not draw variable diagrams for activity 4.b, but did a calculation instead.

Participant 3 only referred to the Program Code box when instructed to do so in the Explanation box. Presumably since he could already program, he did not follow the execution of the `while` loop in activity 9.a.v, but simply clicked to reach the end of the loop, when he did inspect the boxes. He could trace correctly, although he did not follow the conventions of the study guide.

Participant 4 looked puzzled at times, and though he tried to follow, sometimes fixating on code, or reconciling the contents of the Memory box with the program code, it seemed as if he did not always manage to do so. He might not have read or followed all the explanations, since at times his eye movements in the Explanation box were very erratic. It is also possible that he became tired or lost concentration. He did not draw the variable diagrams for the pre-test program, because he could not remember how to do it. The variable diagrams he drew for activity 4.b were partly correct, but the variable diagrams he drew in the retrospective comprehension test, were incorrect. It seemed as if he could not follow the logic of using a control variable that receives a different input value during each loop execution.

Participant 5 seemed to follow the activities and put in some effort to understand it. He read all the explanations and reconciled it with the program code, Memory box, and output in the Console Window and repeated activity 4.a.ii to carefully compare the changes in the Memory box to the program code. When he realized he was getting lost in the logic of a program, he returned to the beginning of the activity to work it again. However, he did not draw variable diagrams for the pre-test and retrospective comprehension test programs. He attempted to draw variable diagrams for activity 4.b, but left out the line numbers, though he did manage to calculate the correct output.

Participant 6 seemed lost and confused, starting an activity and then jumping to another one or returning to a previous activity. He barely glanced at the Explanation box, often only reading one or two lines of the explanations and then veering off to try something else. This participant did not draw any variable diagrams, but instead copied the program code onto paper. He never grasped what to do and did not make a connection between the program code, the explanations, the Memory Box and the Console Window. His feedback on the questionnaire confirmed that as follows: “I don't know how to draw using a computer. I tried to teach myself but no way out”.

Initially *participant 7* did not understand how to use the tutorial, but asked for assistance and thereafter obviously tried to understand, checking and cross-checking code with the Memory box, the Console Window and the explanations. He also used the *Back* button to return and repeat a section if he did not understand it. He actually used the tutorial to assist him in drawing his own variable diagrams for activity 4.b. The variable diagrams that the participant drew for activity 4.b were correct. However, his variable diagrams for the pre-test and retrospective comprehension test programs were not correct, since he did not understand how the `while` loop functions – he ‘executed’ the complete program from declaration of variables to displaying output for each loop iteration. His feedback on the questionnaire confirmed this as follows: “While loops relational operations and while loop bodies still give me challenges in drawing variable diagrams”.

Participant 8 mostly ignored the program code, only glancing at it occasionally and making no connection between the program code, the explanations, the Memory Box and output in the Console Window. This participant did not draw variable diagrams. Instead he drew little diagrams resembling the eye tracker’s screen before recording starts with the program’s input values above it. See Figures 6.21 and 6.22 below.

Participant 9 worked through the activities very quickly, sometimes barely reading anything at all. When he got stuck, he either just clicked the *Next* button without reading or used the *Back* button and the *Index* button to exit from the activity. He did not draw any variable diagrams. He claimed he did work through the study material, but only copied the programs’ code before he worked though the tutorial and declined to draw variable diagrams when requested to do so. This confirms the impression

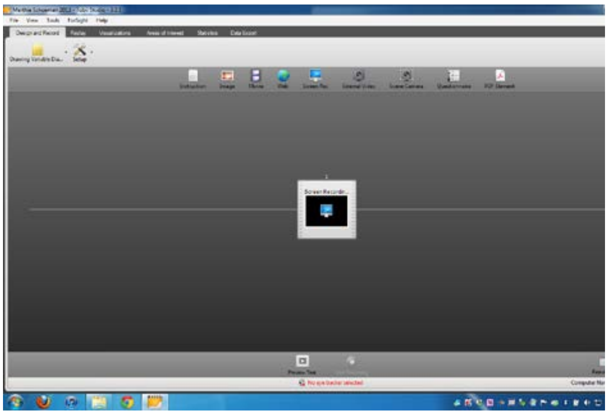


Figure 6.21 Eye tracker's opening screen

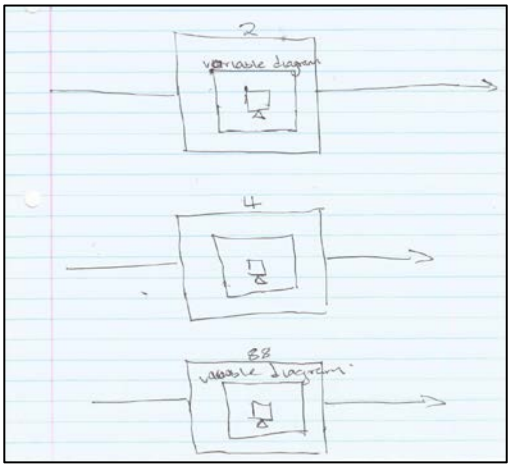


Figure 6.22 Participant 8's attempt at drawing variable diagrams

that he did not master using the tutorial, as does his feedback as follows, on whether he finds it easier to draw variable diagrams after working through the tutorial: "Yes, but it needs more understanding".

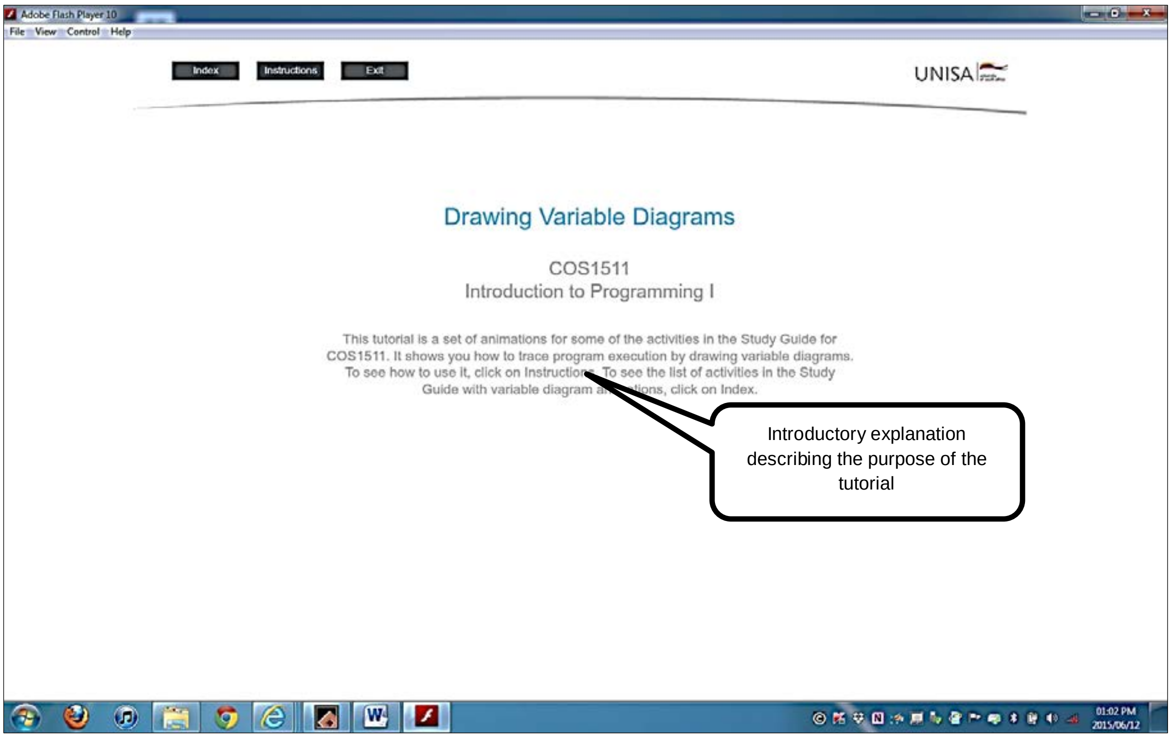
Six participants never reconciled the contents of the four boxes on the screen. This, combined with the descriptions of the participants' behaviour and the variable diagrams drawn by them, confirmed the impression that they did not learn from working through the tutorial. It could be due to the artificial situation in which the observations were done, and the time frame in which it happened, but also because participants did not read program code and/or explanations, or reconciled the four boxes on the screen in an activity.

6.4.3.2 Problems/Issues with the instructions on how to use the tutorial

The instructions in the version of the Drawing Variable Diagrams tutorial used in the first implementation cycle, consisted of a series of screen shots of the introductory frame (called the landing page), the Index page and an activity screen with instructions on what to do on each page (see Appendix D). The landing page is shown in Figure 6.23. The instructions were very brief, simply stating which button to click to choose an activity or exit, and how to navigate through the tutorial.

Only five of the participants read the introductory explanation of the purpose of the tutorial on the landing page (see Figure 6.23). As a result they did not know how to interpret what they saw while working through the tutorial and how it relates to the activities in the study guide.

Five participants read the instructions briefly and one scanned it. Five of the participants who inspected the instructions still experienced problems in navigating the tutorial and seemed lost. Two participants who read the instructions, referred back to it several times to decide how to proceed during, before or at the end of activities. Two participants, who did not study the instructions, also experienced problems using it, confirming the need for instructions. Clearly the instructions were insufficient to explain to participants how to use the tutorial.



Drawing Variable Diagrams

COS1511
Introduction to Programming I

This tutorial is a set of animations for some of the activities in the Study Guide for COS1511. It shows you how to trace program execution by drawing variable diagrams. To see how to use it, click on Instructions. To see the list of activities in the Study Guide with variable diagram animations, click on Index.

Introductory explanation describing the purpose of the tutorial

Figure 6.23 Landing page of first version of the Drawing Variable Diagrams Tutorial

6.4.3.3 Navigation through the tutorial

Problems with navigating through the tutorial were evident in the following five different areas: general navigation problems, using the *Next* button, using the *Back* button, how to continue at the end of an activity and attempts to provide input. However, all participants could use the scroll bars in the four boxes on the screen in an activity to scroll down to see more of the contents in any of the boxes.

General navigation problems were demonstrated by three participants who clicked repeatedly in different places on the screen when they did not know how to proceed. Another participant right-clicked in search of a pop-up menu and one participant tried to use the buttons in the screen prints in the instructions to choose an activity.

Seven of the participants used the *Next* button correctly to proceed to the next frame in an activity, but two did not notice it and asked for assistance on to how to continue. Only one participant used the *Back* button correctly, i.e. to return to a previous frame(s) in order to work through it again. Four participants used the *Back* button to return to the Landing page in order to access the *Index* button to choose another activity. This demonstrates that participants did not recall from the instructions that they had to click on the *Index* button to exit and return to the Landing page at the end of an activity.

Seven participants could not figure out how to continue at the end of an activity. One participant asked for assistance on how to exit from an activity. Another clicked in various places on the screen, and eventually tried the *Index* button, but was only confident that this is the correct way to exit an activity after he had done it several times. The female participant was obviously confused as to what to do on reaching the end of an activity, and when she managed to return to the Landing page by clicking on the *Index* button, used the instructions to confirm that this was the correct action.

Two participants tried to provide their own input values when the program code ‘executed’ an input statement. This probably happened because they did not read the explanation explaining that the tutorial will provide the input, and what the input will be.

In summary, participants could not navigate intuitively through the tutorial without instructions or being instructed on how to do so.

6.4.3.4 Reading skills

Reading is a cognitive-linguistic activity comprising several component skills with decoding and comprehension deemed to be the two main components (Pretorius, 2002). Decoding involves the more technical skills to translate written symbols into language. Comprehension, in contrast, refers to the overall understanding process of constructing meaning from the whole text (Pretorius, 2002; Pretorius & Ribbens, 2005). Effective comprehension depends on good decoding skills. However, good decoding skills alone are not sufficient for effective comprehension (Bertram, 2006). An important part of comprehension is inferencing, that is, the ability to fill in gaps between text elements and link information across textual units (Rickheit, Schnotz & Strohner, 1985). A good reader is in fact a good comprehender (Bertram, 2006).

Eye movements are one of the best methods to study language comprehension processes. Eye movements during reading consist of fixations (pausing eye movement on a specific area), saccades (the movements between fixations) and regressions (saccades that move backwards in the text). Regressions usually occur when the reader finds the text difficult or does not understand what was read. In general the ease or difficulty associated with understanding a word during reading clearly affects how long readers fixate on that word. Readers will fixate longer on less frequently used and/or less predictable words, skip these words less and re-fixate on them more often (Rayner & Pollatsek, 2006).

There may be considerable variation in both fixation and saccade length since text difficulty; reading skills and characteristics of the writing system all influence these values. More difficult text typically causes longer fixations, shorter saccades and more regressions. Beginning, less skilled and dyslexic readers also have longer fixations, shorter saccades and more regressions (Rayner, 2009). Non-English speaking readers have longer fixations and shorter saccades resulting in a decreased reading speed (Beymer, Russell & Orton, 2008). To dyslexic readers, letters may appear to move around so that their vision is unstable (Stein & Walsh, 1997). Mindless reading shows longer and more off-text fixations (Reichle, Reineberg & Schooler, 2010). When combined with other visual material such as images or film, the eye has to move between the text and the rest of the visuals on the screen. This places more demands on attention as information has to be combined from both channels (Hefer, 2013). Results from research by Frazier and Rayner (in Rayner & Pollatsek, 2006) suggest that quickly appearing disruptions in eye-movement control could be used to identify syntactic processing difficulties. The disruptions and regressive eye movements of some participants in the tests in the HCI laboratory may therefore be an indicating of poor comprehension due to poor reading ability.

Judging by their eye movements, *participants 1 and 2* read at a reasonable speed and displayed no obvious reading difficulties. *Participant 3* read well and faster than all the other participants. *Participant 7* read at a reasonable speed and had no problems in reading and comprehending what he had read, since he followed instructions in the Explanation box to look at the Memory box or Console Window without hesitation. All of them also passed the examination at the end of the semester.

Participant 4 looked puzzled at times, and though he tried to follow, sometimes fixating on code, or reconciling the contents of the Memory box with the program code, it seemed as if he did not always manage to do so. He might not have read or followed all the explanations, since at times his eye movements in the Explanation box were very erratic resembling scanning, or displaying a zigzag pattern with frequent regression. It is possible that he became tired or lost concentration, resulting in mindless reading but it could also have occurred due to syntactic processing difficulties or dyslexion.

Participant 5 recommended adding “a zooming tab for those who have difficulties with reading small or medium texts”. The participant had a reasonable reading speed, but sometimes jumped around and reread sentences trying to understand, indicating that he found the text difficult to comprehend.

Participant 6 barely glanced at the Explanation box and may have a problem with reading since when he looked at the Explanation box, he would read one or two lines of the explanations and then veer off to try something else. He also used the mouse to guide his reading. This created the impression that he did not understand or was not a skilled reader.

Participant 8 read slowly, rereading sentences and seemed to struggle to comprehend. His eye movements showed short saccades and long fixations which indicate that either he found the text difficult or was a beginning or dyslexic reader (Rayner, 2009).

Participant 9 went through the activities very quickly, sometimes barely reading anything at all. When he did read, his eye movements often showed fairly short saccades and long fixations, and he sometimes reread text. When he got stuck, he either just clicked the *Next* button without reading or used the *Back* button and the *Index* button to exit from the activity. This could be an indication of poor reading skills.

In summary, participants who could read reasonably well (participants 1, 2, 3 and 7) passed the examination at the end of the semester, while those who displayed inadequate reading skills, did not pass or did not write the examination.

6.4.4 Analysis of the questionnaire completed after eye tracking

The questionnaire that students completed after the eye tracking and observations in the HCI laboratory is shown in Appendix C. Five participants indicated that they had used the Drawing Variable Diagrams Tutorial before. Four of the participants indicated that they had drawn variable diagrams before and stated that they found it easier to do after they had used the tutorial, since it showed how to do so line by line, and was seen as a simple and quick way to refresh one's memory. Two of the four who had drawn variable diagrams before said that they drew variable diagrams occasionally to help them understand programs in the Study Guide, while the other two said that they had not done so in the past, but intended to do so in future. Of the five participants who indicated that they had never drawn variable diagrams before, three nevertheless claimed to draw variable diagrams to help them understand the programs in the Study Guide. This may be an indication of the experimenter effect, when participants attempt to react in a way that they think the researcher expects them to, due to subtle unconscious clues given by the researcher about what he or she expects (Oates, 2006; Terre Blanche et al., 2006), or simply that the participants did not understand the questions.

All the participants agreed that the questions in the activities helped them to concentrate or understand the variable diagrams, even if it was "only a little bit". Five participants wanted auditory explanations, one would have liked to have it available occasionally and three preferred not to have it. Of the participants who would have liked auditory explanations, two failed the end-of-semester examination; two participants did not write the examination and one passed. This may be an indication that those with poorer reading skills may wish to have auditory explanations to compensate for their reading skills.

The participants made the following suggestions to improve the tutorial:

- Placing the Explanation box before the written program
- Indicating the end of an activity more explicit with instructions on how to continue
- Making the Next button more prominent
- Clarify what to do in the tutorial, e.g. to click the Next button to continue
- Auditory explanations for more difficult parts
- Adding a zooming tab for small text

Two students still found it difficult to understand `while` loops and one found incrementing a loop variable confusing.

The results of the direct live observation and eye tracking in the HCI laboratory during this research are summarised as follows:

- During the gaze replays, it became evident that the most obvious usability problems were how to navigate the tutorial and how to learn from the tutorial by reconciling the four boxes containing or representing the program code, the explanations, the CPU memory and the console window.
- Factors that could have contributed to this situation include: not reading the introductory explanation explaining the purpose of the tutorial; inadequate instructions; not reading the explanations or ignoring the program code, Memory box or Console Window; and participants who experienced problems with reading itself. The fact that five participants wanted audio explanations, with two more requesting it as an option, confirms that reading itself may be a factor to be taken into account.
- In general, the participants who used the tutorial as intended had better reading skills and passed the examination at the end of the semester (participants 1, 2, 3 and 7), while those who struggled either failed or did not write the examination (participants 4, 6, 8 and 9). Participant 5 seemed to make an effort to understand, but he did not draw variable diagrams. He also failed the examination. He displayed a reasonable reading speed, but seemed to have problems comprehending.

6.4.5 Update of tutorial based in analysis of the eye tracking and accompanying questionnaire completed after eye tracking

Based on the observations in the HCI laboratory and the participants' recommendations, the Drawing Variable Diagrams tutorial was updated as follows:

- The instructions were expanded into a presentation explaining what a variable and a variable diagram is; the purpose of variable diagrams and the tutorial; the relationship between the activities in the tutorial and the study guide; how to use the tutorial including a description of the purpose of the various pages in the tutorial, an explanation of an activity screen, the four boxes in an activity screen, the relationship between them and how to reconcile them; as well as a walk-through of activity 3.a showing how to reconcile the boxes; and some notes on how to proceed at the end of an activity. The instructions for the subsequent version of the Drawing Variable Diagrams Tutorial are shown in Appendix E.
- A button 'How to use this tutorial' was placed immediately below the introductory explanation on the introductory frame (landing page) leading to the instructions.
- The Next and Back buttons were made more prominent by giving them an outline and writing 'Next' and 'Back' below the buttons themselves.

- A Finished button replaced the Next button at the end of an activity and a prompt was placed inside the Explanation box to tell users ‘Click Index button to go back to list of activities.’
- An explicit explanation that users need not provide any input was put in the explanations at the beginning of activity 3.a as well as in the instructions.
- The number of iterations in all looping activities such as the for loop in activity 9.a.v, was decreased to reduce the complexity.
- Minor changes to repair small errors picked up such as incomplete highlighting of lines in the Program Code box.

The changes to the tutorial were all intended to improve its usability, with the main focus on providing detailed instructions on how to use it.

6.5 Feedback from students in first implementation cycle

Towards the end of both the first and second semester in 2012, students were invited on the online forum for COS1511to provide feedback on their experience of using the Drawing Variable Diagrams tutorial. Unfortunately a very small number of students responded. Six students posted positive responses, six responded negatively, five used the opportunity to complain about the Study Guide or assignments, and one admonished other students for not putting in more effort into mastering the module.

Under the positive feedback four respondents stated explicitly that they found the tutorial helpful. One of them said that he had never seen program code before and commented – “I was able to write, analyse, compile, run, and troubleshoot/debug without help from anyone.” Another appreciated being able to – “see how things work ‘inside’”. The following feedback from three students confirmed that drawing variable diagrams assists in creating a mental model of program execution:

- “Once you understand the drawing of the diagrams is the visualization of the logic in your program the need for it and the understanding of it is much clearer. Using the CAI tutorials also improved my understanding of them a whole lot better. It is definately (sic) very very helpful.”
- “I found that once the conventions (as in the study guide) became second nature, it allowed me to ‘compile’ the source code mentally, which is obviously an important skill to have. It is a novel concept as far as I am concerned, the likes of which I never really considered.”
- “I must say I found that the variable diagram tutorial was really well written and easy to follow. Also it helped me in following how variables change at each stage of the program. I have managed to resolve some logic issues in my practice code by drawing up variable diagrams. It seems to be one of the most important tutorials in the book.”

Under the negative feedback, two students complained that the tutorial was not easy to follow for novices and another that he sometimes could not execute it (without any further elaboration as to why he could not execute it). One student said it was easy to understand, but too basic. Two other students also said it was too basic, since it did not cover the questions in the assignments. The following two comments probably came from students who struggled:

- "Tutorial is helpful to someone who did computers at school and very difficult to understand if one has never done computers. I managed assignment one with the help from someone who did computers at school. Now that the person is gone I am finding it difficult to do it alone. I cannot rectify errors on C++ since there are no examples of errors shown in the tutorials."
- "I find out this tutorial is some how not helping me out to pass this module, because i have been trying my best several time but i always get dissapointed.
  1. The assignments are to far from what we have in our study guide.
  2. The exam structure is always changing, which is difficult to understand comparing to the basic tutorial that we must prepare for the exam."

The general tone of the negative responses shows that some students did not understand the purpose of the tutorial. They expected it to help them in doing their assignments, instead of showing them how to draw variable diagrams for each new programming construct they learn. Tellingly, the responses from students who found drawing variables and the tutorial beneficial implied that they spent time to master it. This confirms that engagement with visualization is key to its success.

6.6 Findings

As discussed in section 6.3.1 the findings from the first implementation cycle will not be generalised, but should hold, with caution, for those COS1511 students who wrote the examination in 2012.

The quantitative investigation discussed in sections 6.2 and 6.3 aimed to answer the second and third research questions. In section 6.2, it was established that the findings by the BRACElet project regarding the correlation in performance between 'explain in plain English' tasks and code writing tasks as well as between code tracing and code writing tasks (Lister et al., 2009; Lopez et al., 2008) are also applicable to the participants in this study. This confirmed that an improved ability to trace should have had a positive effect on a student's marks.

The following factors impacting on students' final marks were explored in section 6.3:

- Mathematics and English marks;
- biographical properties as summarized in the set of profile scores;
- a positive user experience when using the tutorial;
- students' prior experience of programming;
- their use of tracing; and

- the time they spent using the tutorial.

The mean percentages for Mathematics for students in both semesters were 51% and 52% respectively, and for English 53% and 54% respectively. This indicated that students did not have a strong Mathematical or English background, which was also evident in the poor reading skills some participants demonstrated during the eye tracking and observation in the HCI laboratory.

Students' biographical properties were expressed in a profile score comprised of their prior programming experience, Grade 12 marks for Mathematics and English, and first-time registration for COS1511 or not. The majority of both first and second semester students obtained a profile score of between zero and two (56% and 70% respectively), indicating that most were not academically strong.

Students expressed a positive user experience, 3.75 for the first semester and 3.68 for the second semester.

The first semester students in general did better than second semester students, as the mean final marks for the two semesters confirm (47% in the first semester and 42% in the second semester).

In both semesters, the majority of students had not drawn variable diagrams before enrolling for COS1511, but claimed to use the tutorial and to draw their own variable diagrams to understand the programs in the Study Guide. Approximately half of them drew their own variable diagrams to debug their programs.

The relationship between students' final mark and the following factors that could possibly affect it, was modelled with multiple linear regression and refined with stepwise multiple linear regression for both semesters:

- Biographical profile of respondents as summarized in the set of profile scores.
- User experience as measured by the positive user experience scores.
- Prior use of variable diagrams (q12).
- Using the tutorial or not (q13).
- Drawing variable diagram to understand programs in the Study Guide (q14).
- Drawing variable diagrams to debug (q15).
- Time spent using the tutorial (q16).

These models were also fitted with decision trees. The multiple linear regression and the decision tree models for both semesters showed that students' biographical properties (prior programming experience, Mathematics and English marks, and first registration or not for COS1511) had by far the biggest impact on their final marks. ANOVA models for both semesters confirmed that students who were employed as programmers and were therefore classified as being experienced in programming, achieved the highest marks. The ANOVA models for both semesters also confirmed that students who spent less than one hour using the tutorial, achieved the highest marks.

The quantitative investigation therefore indicates that the tutorial did not assist students in acquiring programming skills (research question 2). Students who used the tutorial achieved lower marks than those who did not. The multiple linear regression analysis shows that use of the tutorial did not have an effect in the first semester but did have an effect in the second semester. This might be due to the composition of the data set, and may well vary for a larger data set in either of the semesters. The factor that had the biggest positive impact on a student's final mark (research question 3), was his or her biographical properties as represented by the profile score while having drawn variable diagrams before contributed to a lesser degree to a better final mark. A positive user experience did not contribute to a higher final mark and students drawing their own variable diagrams, while working through the Study Guide had almost no impact.

The qualitative investigation discussed in sections 6.4 and 6.5, aimed to enhance the answers to research questions 3 and 4, by investigating students' interaction with the tutorial as well as their user experience of it. The direct live observation and eye tracking of participants discussed in section 6.4, revealed the following problems:

- students did not really learn how to draw variable diagrams from using the tutorial;
- the instructions on how to use the tutorial were insufficient;
- students could not navigate intuitively through the tutorial; and
- lack of reading skills hampered understanding and learning from the tutorial.

A very small number of students provided feedback on the COS1511 discussion forum, as discussed in section 6.5. Nevertheless, the positive feedback indicated that students, who spent enough time engaging with it, believed they benefited from it. Negative feedback confirmed that novices did not find it easy to use the tutorial, and that students misunderstood the purpose of the tutorial, since they expected that it would assist them in doing their assignments.

The qualitative investigation confirmed the findings from the quantitative investigation in answer to research question 2, namely that students did not learn from using the tutorial in its initial version.

The qualitative investigation also confirmed the findings of the quantitative investigation in answer to research question 3, namely that students' educational background as expressed in the biographical profile score, contributed largely to their final marks for COS1511. Students in the qualitative investigation who could read well, performed better in the examination, and found using the tutorial easier. Lack of reading skills, tie in with the mediocre means in participants' marks for English and Mathematics in matric. Inadequate instructions for using the tutorial were partly to blame for students' struggle to navigate through the tutorial and as a result, not learning from the tutorial, while lack of reading skills contributed to this.

With regard to research question 4, the qualitative investigation revealed two important lessons, namely that –

- students should be made aware of the purpose of a visualization; and
- they should receive detailed instructions on how to use it, especially if they are expected to do so on their own, as in an ODL environment.

In preparation for the second cycle the deficiencies in the tutorial were addressed. In section 6.4.4 it was described how this was done, while the second implementation cycle as such is discussed in Chapter 7.

6.7 Summary and conclusion

This chapter described the quantitative and qualitative investigations of the first implementation cycle of testing and refinement of the tutorial to teach students to draw variable diagrams. The aim was to provide answers to research questions 2, 3 and 4 of this research investigation. The quantitative investigation was discussed in sections 6.2 and 6.3, while the qualitative investigation was addressed in sections 6.4 and 6.5.

The quantitate investigation included verifying that the findings from the BRACElet project (Lister et al., 2009; Lopez et al., 2008) regarding the relationship between students' abilities to explain code in plain English and to trace code as well as the combination of these skills, and their final marks for COS1511. The purpose of this was to confirm that an improved ability to trace should assist students in acquiring programming skills. As discussed in section 6.2, the findings from this study confirmed this.

In section 6.3, the relationships between factors that could influence a student's final mark and his/her final mark were investigated to determine how students' interaction with the tutorial affected their final marks. The results indicated that a student's profile score (consisting of respondents' programming experience, their Grade 12 (Matric) English and Mathematics levels and first-time COS1511 registration) had the largest influence on their final mark. Being employed as a programmer also had a significant effect on a student's final mark. Having drawn variable diagrams before enrolling for COS1511 had a small positive effect on a student's examination mark. Time spent on using the tutorial did not have a positive effect. Students who drew their own variable diagrams to help them to understand programs in the Study Guide, actually achieved lower examination marks than those who did not do so.

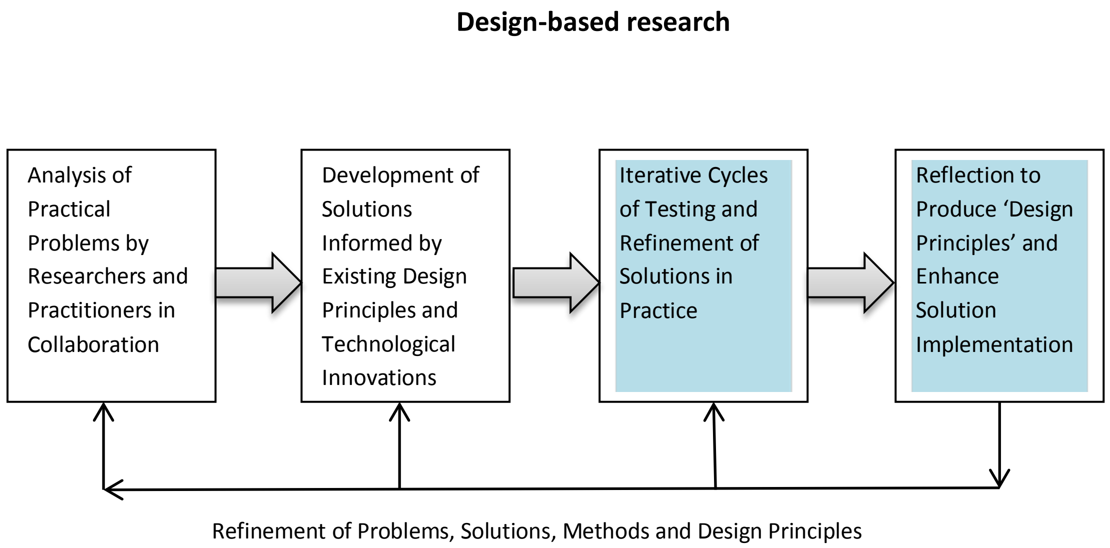
The qualitative investigation with direct observation and eye tracking in the HCI laboratory described in section 6.4, confirmed the findings from the quantitative investigation, and added valuable insight by revealing that lack of reading skills played a role in a student's use of, and possible benefit from the tutorial. It also exposed deficiencies in the tutorial linked to inadequate instructions on using the tutorial. Poor reading skills are probably linked to lower marks for English.

The feedback from the COS1511 discussion forum as presented in section 6.5, confirmed that novices found it difficult to learn from the tutorial and did not understand what the purpose of the tutorial is. Students who engaged deeply enough with the tutorial, on the other hand, reported benefitting from it.

In section 6.6 the findings from this first implementation cycle were discussed. In summary, the answer to research question 2 was that the tutorial did not assist students in acquiring programming skills in Unisa's ODL environment so that it is noticeable in average marks. The answer to research question 3 revealed that students' biographical background as expressed in their profile score played by far the biggest role in their final mark. Two important lessons were learnt in answer to research question 4, namely that students need be made aware of the purpose of the tutorial and should receive detailed instructions on how to use it.

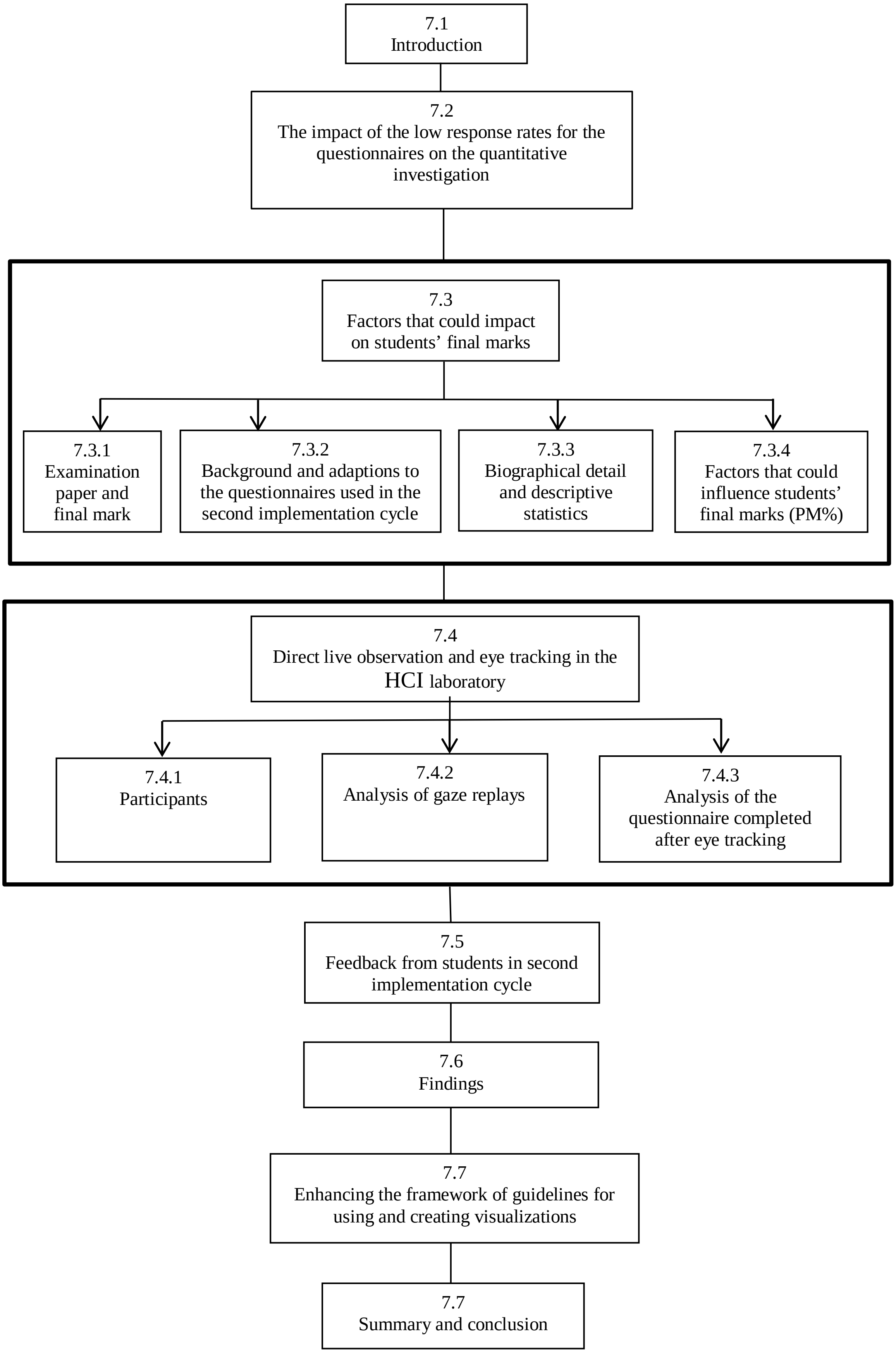
The next chapter describes the second implementation cycle of testing and refinement of the tutorial to teach students to draw variable diagrams to assist in shedding more light on the findings from this chapter.

Design-based research phase covered in Chapter 7


Design-based research
Analysis of Practical Problems by Researchers and Practitioners in Collaboration
Development of Solutions Informed by Existing Design Principles and Technological Innovations
Iterative Cycles of Testing and Refinement of Solutions in Practice
Reflection to Produce 'Design Principles' and Enhance Solution Implementation
Refinement of Problems, Solutions, Methods and Design Principles

Phase	**Element**	**Position**
Phase of design-based research (Reeves, 2006)	*Topics/elements that need to be addressed*	*Position in this thesis*
PHASE 1: Analysis of practical problems by researchers and practitioners in collaboration	Statement of problem	Chapter 1, Section 1.3.1 Chapter 4, Section 4.3.2.1
	Consultation with researchers and practitioners	Chapter 4, Section 4.3.2.1 and section 4.3.4.3
	Research questions	Chapter 1, Section 1.3.3 Chapter 4, Section 4.3.2.3
	Literature review	Chapters 2 and 3, Section 5.2
PHASE 2: Development of solutions informed by existing design principles and technological innovations	Theoretical framework	Chapter 5, Section 5.2
	Development of draft principles to guide the design of the intervention	Chapter 5, Section 5.3
	Description of proposed intervention	Chapter 5, Section 5.5
PHASE 3: Iterative cycles of testing and refinement of solutions in practice	Implementation of intervention (First iteration) Participants Data collection Data analysis	Chapter 6
	Implementation of intervention (Second and further iterations) Participants Data collection Data analysis	Chapter 7
PHASE 4: Reflection to produce 'design principles' and enhance solution implementation	Design principles	Chapters 5, 6 and 7
	Designed artefact(s)	Available on course website
	Professional development	Chapter 8

Map of Chapter 7 (Second implementation cycle of the Drawing Variable Diagrams Tutorial)


7.1
Introduction
7.2
The impact of the low response rates for the questionnaires on the quantitative investigation
7.3
Factors that could impact on students' final marks
7.3.1
Examination paper and final mark
7.3.2
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Chapter 7 Second implementation cycle of the Drawing Variable Diagrams Tutorial

7.1 Introduction

This chapter describes the second implementation cycle of testing and refinement of the tutorial to teach students to draw variable diagrams in 2013, as shown in Table 4.3. The first implementation cycle was covered in the previous chapter.

As did Chapter 6, this chapter has the purpose of addressing the second, third and fourth research questions, namely:

2. Will a tutorial to teach tracing to visualize program execution and parameter transfer, based on the framework of guidelines, assist students in acquiring programming skills in an ODL environment so that it is noticeable in average marks?
3. How do students' biographical properties, their positive user experience, their use of tracing and the extent and manner of tutorial use, affect their ability to acquire programming skills in an ODL environment?
4. What lessons have been learnt through the practical testing and refinement of the visualization tool?

In Chapter 6 it was found that the tutorial did not assist students in acquiring programming skills. Several deficiencies in the tutorial itself may have been the cause of this finding. The tutorial was adapted according to the findings from the direct live observations and eye tracking done in an HCI laboratory as described in section 6.4.4. See screen dumps of the second version of the tutorial in the walk-through on how to use the tutorial in the updated instructions in Appendix E. The questionnaires used were also adapted to request more feedback regarding students' experience of using the tutorial (see section 7.3.2).

During the second implementation cycle both the quantitative and qualitative investigations were repeated to investigate whether the adaptions to the tutorial succeeded in improving the students' learning experience while using the tutorial; what the effect thereof was on their final marks; and what lessons could be learnt from this. As before, the quantitative investigation aims at answering the second and third questions, while the reflection on the data analysis together with the qualitative investigation answers question 4.

The data collection and analyses for both the quantitative and qualitative investigations followed the same approaches as in the first implementation cycle. (See sections 6.1.1 and section 6.1.2 for a review of these approaches). Note that due to a new regulation introduced by Unisa Management on the manner in which questionnaires may be distributed to students, with effect from 2013, questionnaires were no longer allowed to be included with assignments. Instead, students had to be invited via e-mail to complete the questionnaires on the course website. As a result the response rate was far less than in the first implementation cycle, so that the numbers of responses were too small to repeat the modelling that was done in the statistical analysis for the first implementation cycle. The impact this had on the quantitative investigation is described in section 7.2.

The quantitative investigation is described in section 7.3, while the qualitative investigation is discussed in sections 7.4 and 7.5. The findings from this implementation cycle are discussed in section 7.6, and in section 7.7 the framework of guidelines for using and creating visualizations is refined by incorporating the lessons learnt during the research effort. In section 7.8 the summary and conclusion is presented.

7.2 The impact of the low response rates for the questionnaires on the quantitative investigation

The intention was to repeat and expand the quantitative investigation done, during the second implementation cycle. This would have entailed investigating –

- the relationships between students' abilities to explain the purpose of code and to trace, and their final marks, as well as the relationship between the combination of students' ability to explain code and to trace and their final marks to establish whether the findings of the BRACElet project (Lister et al., 2009; Lopez et al., 2008) also applied to the 2013 participants; and
- modelling the relationships between the final mark and the same factors investigated in the first implementation cycle that could possibly influence it, as well as two additional factors, namely the manner in which students used the tutorial and their perception of learning from the tutorial.

As mentioned in section 7.1, questionnaires could not be included with assignment questions and students had to be invited via e-mail to complete the questionnaires on the COS1511 course website. Despite repeated e-mails and announcements sent to the students requesting them to complete the questionnaire, the response rates were far less than in the first implementation cycle.

In the first semester of 2013, 294 of the 1 623 students registered for COS1511, completed the first questionnaire, giving a response rate of 18%. The second questionnaire was completed by 142 students, giving a response rate of 9%. Eighty-five students completed both the first and second questionnaires. In the second semester 176 of the 1 593 students registered for COS1511, completed the questionnaire, giving a response rate of 11%.

Using the final mark for COS1511 (PM%) as the dependent variable in the statistical analysis, reduced the population size to the number of students who wrote the examination. Therefore the population size for the first semester in 2013 was 988 and for the second semester in 2013 it was 920 (see Table 1.1 in section 1.1). For these population sizes a sample of 278 responses would have been required in both cases to be representative of a given population when random sampling is done, according to the table provided by Krejcie and Morgan (1970:608) and Johnson and Christensen (2004:218).

Similar to the first implementation cycle, only respondents who submitted both assignments and wrote the examination; and for whom matric marks for Mathematics and English could be obtained from the Unisa student system, were included in the analysis. In the first semester of 2013, 66 respondents satisfied these conditions, allowing statistical analysis of 46% of the respondents. In the second semester 76 respondents satisfied these conditions, allowing statistical analysis of 43% of the second-semester respondents. However, these small numbers of responses were clearly not representative of the populations. As a result only descriptive statistics could be calculated for the quantitative investigation in the second implementation cycle. The relationships between students' abilities to explain the purpose of code and to trace, and their final marks, as well as the relationship between the combination of students' ability to explain code and to trace and their final marks could therefore not be investigated. The relationships between the final mark and the factors that could possibly have influenced it could also not be investigated.

In order to examine the factors that could have affected a student's final mark, albeit only with descriptive statistics, only the second questionnaire in the first semester was considered. The second questionnaire included all the questions that were used in the first questionnaire, which were also used in the first implementation cycle in 2012. This covered all the factors that were investigated in the first implementation cycle. The second questionnaire in the first semester as well as the only questionnaire in the second semester included two more factors namely the manner in which students used the tutorial throughout the semester, and their perception of how much they learnt from using the tutorial. These two questionnaires were the same, except for the first question in the second questionnaire for the first semester, that was used to determine whether students had answered the first questionnaire in the first semester. Since the second questionnaire in the first semester and the only questionnaire in the second semester were both administered at the end of the semester, the two questionnaires could be processed in the same way. This provided more insight into the manner in which students used the tutorial.

In the next section factors that could have influenced students' final marks are discussed, including the composition of the examination papers and final marks for 2013 and the questionnaires used in 2013.

7.3 Factors that could impact on students' final marks

In section 6.3 a number of factors from the literature that may have a positive or negative influence on introductory programming students' performance were discussed. Recall that factors that can affect a student's marks positively include –

- formal training or prior experience as a programmer (Byrne & Lyons, 2001; Wilson & Shrock, 2001);
- existing problem-solving skills developed in subjects such as Mathematics and Science (Bennedsen & Caspersen, 2005a; Chmura, 1998; Pillay & Jugoo, 2005; Wiedenbeck, 2005);
- past performance in Mathematics (Bergin & Reilly, 2006; Byrne & Lyons, 2001; White & Sivitanides, 2003; Wilson & Shrock, 2001); and
- programming behaviour such as time spent debugging (Watson et al., 2014).

Factors that can affect students' marks negatively include poor reading skills (Cliff, 2015; Gous & Roberts, 2014; Hefer, 2013; Kilfoil, 2008; Nel et al., 2004) and having to learn to program to program in a second or third language (Carter et al., 2007; Gous & Roberts, 2014; Pillay & Jugoo, 2005).

Similar to the investigation in the first implementation cycle, students' responses to the multiple-choice questionnaires were categorised according to probable explanatory effects or factors that could impact on their final marks. Since the numbers of responses for both semesters were too small (see section 7.2), modelling could not be done and as a result, only descriptive statistics for the factors that could have impacted on a student's final mark are provided.

In the sections below the composition of the examination paper and the final marks; the background and adaptions to the questionnaires used in the second implementation cycle; the biographical detail and descriptive statistics of respondents as well as the various factors that could have influenced a student's final mark for COS1511 are discussed.

7.3.1 Examination paper and final mark

The examination papers for 2013 used a similar format to 2012, as presented in Table 7.1. The final marks were composed in the same way as in 2012. The final mark for each student was comprised of the sum of the marks for the MCQs in Part A (marked electronically) and the questions in Part B of the examination paper, plus the year mark. The first two questions were intended to explore students' abilities to explain code in 'plain English' and to trace while the other questions focused on assessing their programming ability.

Table 7.2 shows the mean percentages and standard deviations achieved by respondents for questions 1 to 8 in Part B of the two semester examinations in 2013. In semester 1, question 5 (writing nested `if` statements) had the highest mean percentage, question 3 (writing a `switch` statement) had the

Table 7.1 Structure: Part B of COS1511 examination papers in 2013

Question number	Topic	Marks allocated
1	Explain the purpose of two short code fragments.	4
2	Use variable diagrams to trace parts of two programs (a program using the `switch` statement and a program call to a function with value and reference parameters), and indicate what the output will be.	11
3	Write a `switch` statement	5
4	Complete a program by writing a `while` loop and `if` statement.	7
5	Write a complete a program using nested `if` statements.	6
6	Write a function using a one-dimensional array.	6
7	Complete a program to declare a two dimensional array and determine the sum of each row in the array.	8
8	Write function headers; convert a `void` function to a non-`void` function; write function calls; and write and call a small function.	12
9	Give the output for statements to print the values of the components of a struct and write a function to input values for the components of a struct.	6
10	Short questions in which students had to use string member functions.	5

second-highest mean percentage, and question 2 (tracing) the third-highest. In semester 2, question 5 (writing nested `if` statements) had the highest mean percentage, question 2 (tracing) had the second-highest mean percentage, and question 3 (writing a `switch` statement) the third-highest.

Table 7.2 Mean percentages and standard deviations of marks achieved by respondents for questions 1 to 10 in Part B of the two semester examinations in 2013

	Semester 1 2013 N= 66		**Semester 2 2013 N = 76**	
	Mean	**Std Dev**	**Mean**	**Std Dev**
Q1 %	39.7	30.9	48.8	35.9
Q2 %	50.2	23.8	63.1	23.6
Q3 %	60.0	39.1	62.9	41.5
Q4 %	53.8	34.8	42.6	26.4
Q5 %	62.6	39.9	95.3	42.8
Q6 %	33.0	36.8	56.5	36.0
Q7 %	31.5	32.5	44.4	38.3
Q8 %	34.9	36.2	46.3	35.6
Q9%	28.8	35.4	40.1	38.6
Q10%	11.0	22.3	31.1	45.4

For the first semester in 2013 the final marks varied from a lowest mark of 33% to the highest mark of 93% with the median of 60%. The mean for the final marks for the first semester 2013 was 61.15% and the standard deviation 15.33. For the second semester the final marks varied from a lowest mark of 9.14% to the highest mark of 94.09% with a median of 57.53%. The mean for the second semester 2013 was 54.72% and the standard deviation 24.72. Supporting tables are shown in Appendix D.2.1.

Although it appears as if second-semester respondents did consistently better than first-semester respondents in all questions, both the mean and the median for the first semester were higher than the mean and the median for the second semester. As can be seen from Figures 7.1 and 7.2, the final marks for the respondents in the first semester 2013, had a more normal distribution than those of respondents in the second semester of 2013. This explains the apparent anomaly between the lower mean and median despite apparently consistently higher marks per question for the second semester respondents.

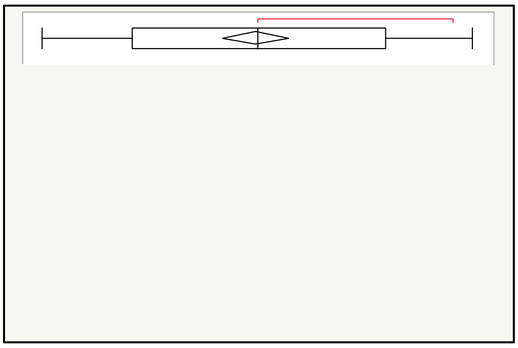


Figure 7.1 Distribution of final marks for respondents in semester 1 2013

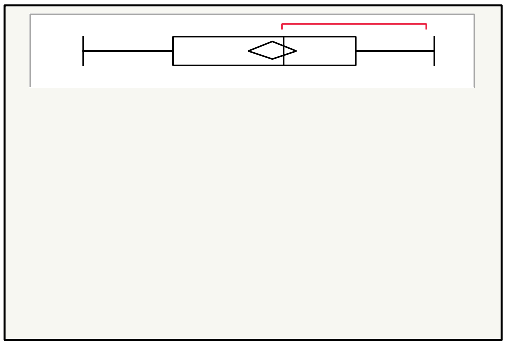


Figure 7.2 Distribution of final marks for respondents in semester 2 2013

7.3.2 Background and adaptions to the questionnaires used in the second implementation cycle

The questionnaire administered in the first semester of 2012 was modified for the second implementation cycle to clear up possible misunderstandings from students as well as to make provision for options that were not available in the original questionnaire. In particular, all references in the questionnaires to 'the tutorial' were changed to 'the Drawing Variable Diagrams Tutorial' in order to eliminate any possibility of confusion with other tutorials the students might have encountered. For all questions that use a Likert scale (Oates, 2006), the responses were changed to be uniform. These responses now read 'Not at all', 'Not really', 'Undecided/Neutral', 'To some extent' and 'Definitely'. In addition, a number of questions were added to explore the manner in which students used the tutorial throughout the semester, and their perceptions of how much they learnt from using the tutorial.

In the first semester of 2013 two questionnaires were administered, one directly after students had to submit the assignment, and another towards the end of the semester, since the response rate to the first questionnaire was very poor. The second questionnaire for the first semester included all the questions from the first questionnaire. In the second semester only the latter questionnaire was administered towards the end of the semester, in the hope of a better response rate. These questionnaires are shown in Appendix B.2.

Note that the only difference between the second questionnaire in the first semester of 2013 (see Appendix B.2.1.2) and the only questionnaire in the second semester of 2013 (see Appendix B.2.2) was question 1 that enquired whether respondents completed the first questionnaire in semester 1 of 2013. Respondents, who had done so, could skip questions 2 to 12 in the second questionnaire in the first semester. These questions were related to their biographical background, computer literacy and programming experience. The responses from respondents who answered the first questionnaire, to these questions were carried over to the corresponding questions in the second questionnaire.

Since question 1 in the second questionnaire of the first semester did not contribute any relevant information to the statistical analysis, the question numbers as used in the only questionnaire in the second semester are used when referring to questions. This is the case both when discussing adaptions to questions or to indicate which questions were used to characterise factors.

The questionnaires included similar questions as in 2012 on biographical data (questions 1 to 8); students' computer literacy, programming experience and registration for COS1511 (questions 9 to 11); questions related to their use of the tutorial and drawing variable diagrams (questions 12, 13, 16, 17 and 22); and questions on user experience (questions 37 to 41). New questions were incorporated to determine students' perception of how much they learnt from the tutorial (questions 18, 19, 23 to 36, 42 and 43), as well as the manner in which they used the tutorial (questions 14, 15, 20 and 21).

Additional options were included in questions 3, 9 and 10. An option 'Other' was included in question 3 to allow for situations related to studying full-time or part-time that were not addressed in the previous version of the question. Similarly, in questions 9 and 10 two additional options 'None' and 'Other' were included to provide for respondents who were not computer-literate or who had no programming experience; or who had a means of computer literacy development or programming experience not covered by the remaining options.

An explanation of what tracing is, was added to question 36 (question 17 in the questionnaire for the first semester in 2012), in which respondents had to indicate the degree to which the tutorial assisted them in mastering tracing. The time ranges in question 22 (question 16 in the questionnaire for the first semester 2012) were expanded since respondents had to complete the questionnaires at the end of the semester.

In Table B.3.1 in Appendix B.3 the questionnaire administered in the first semester of 2012 is compared with the questionnaires used in the second implementation cycle. It also shows how the questions in the questionnaires were classified to explore various constructs or factors that could have had an effect on the final marks of students.

7.3.3 Biographical detail and descriptive statistics

The biographical detail for both the 2013 first- and second-semester respondents to the questionnaire is shown in Table D.2.3. The majority of the respondents were male – 65% in the first semester and 72% in the second semester. In the first semester most of the respondents were between 19 and 27 years of age (68%), while in the second semester most respondents were slightly older, between 23 and 32 years old (57%).

In the first semester 24% of respondents were full-time students who did not work at all, while 13% of second-semester respondents were full-time students who did not work at all. In the first semester 70% of the respondents worked full-time and 43% worked in a field related to their degree. For the second semester similar ratios worked full-time (72%) and worked in a field related to their degree (45%). Note that this does not imply that their work involved programming, since COS1511 is offered to a number of different degrees and diplomas in various faculties. The remainder worked part-time.

Matric was the highest qualification for most respondents (58% in the first semester and 64% in the second semester). The proportion of respondents who had national certificates, diplomas and degrees in the two semesters were comparable. Thirteen per cent of first-semester respondents and 16% of second-semester respondents had national certificates while 17% of first-semester respondents and 16% of second-semester respondents had a diploma. Four per cent of first-semester respondents and 3% of second-semester respondents had a degree. In the first semester 8% of respondents had a post-graduate degree, and in the second semester 2%.

In both semesters English-speaking respondents comprised the largest group (46% in the first semester and 43% in the second semester). In the first semester 32% of respondents had Afrikaans as their first language and in the second semester 29% had Afrikaans as their first language. A bigger proportion of the second-semester respondents had another language as their first language (28% in comparison to 21%).

In the first semester 63% of respondents indicated that they passed Mathematics with a C symbol on Higher or Standard grade, while 78% indicated the same in the second semester. In the first semester

all of the respondents had Mathematics in matric, while one person in the second semester (2%) did not have Mathematics in matric. In the first semester 57% of respondents indicated that they passed English with a C symbol on higher or standard grade, and 70% of second-semester respondents indicated the same. In both semesters all respondents had English for matric. There is a possibility that students may not have understood what a C symbol means, or the difference between higher and standard grade, since only 41 of the 66 respondents in the first semester and 50 of the 76 respondents in the second semester completed the questions on their matric results for Mathematics and English.

In the first semester 43% of the respondents had Computer Applications Technology, Information Technology or Computer Studies at school and in the second semester 52%. Twenty-two per cent of first-semester respondents and 34% of second-semester respondents did some form of computer literacy course. Twenty-eight per cent of first-semester respondents and 29% of second-semester respondents used a computer daily at work. In both semesters 15% of respondents ascribed their computer-literacy to taking Computer Applications Technology, Information Technology or Computer Studies at school. A relatively large part of respondents, 31% in the first semester and 20% in the second semester, were self-taught. Four per cent of first-semester respondents and 6% of second-semester respondents had other means of exposure to computer-literacy.

7.3.4 Factors that could influence students' final marks (PM%)

The same factors or independent variables that were investigated for their influence on the dependent variable, namely the final mark for each student, as in the first implementation cycle, were examined in this implementation cycle. Two additional factors to represent students' manner of tutorial use, and their perception of how much they learnt from the tutorial, were also included. The factors investigated and discussed below, were therefore the students'–

- Mathematics and English marks;
- profile scores;
- manner of their tutorial use;
- prior experience of programming and use of tracing;
- experience of learning from the tutorial; and
- positive user experience.

7.3.4.1 Mathematics and English marks

The statistical analysis in the first implementation cycle has shown that students' Mathematics and English marks as part of the profile score play an important part in contributing to their final marks. As in the first implementation cycle, the respondents' Grade 12 English and Mathematics results as obtained from the Unisa student system were included in the profile score. A mark of 60% or more was again used as the cut-off level for both English and Mathematics.

Figure 7.3 and Figure 7.4 respectively show the frequency distribution of respondents' marks in Mathematics for the first and second semesters in 2013. The mean percentage for Mathematics obtained by first-semester respondents was 61.15%, with a standard deviation of 15.33; and for second-semester respondents the mean percentage was 61.72%, with a standard deviation of 14.74. Supporting tables for both semesters are shown in Appendix D.2.3.

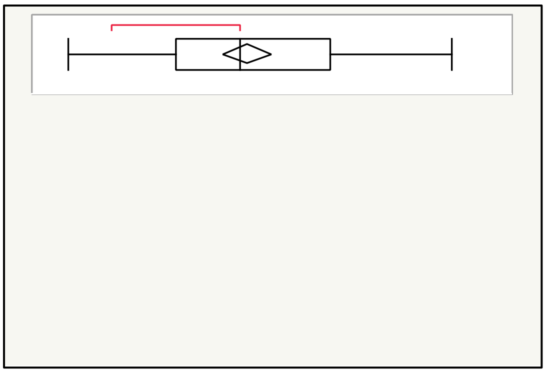


Figure 7.3 Distribution of Mathematics marks obtained by 2013 semester 1 respondents

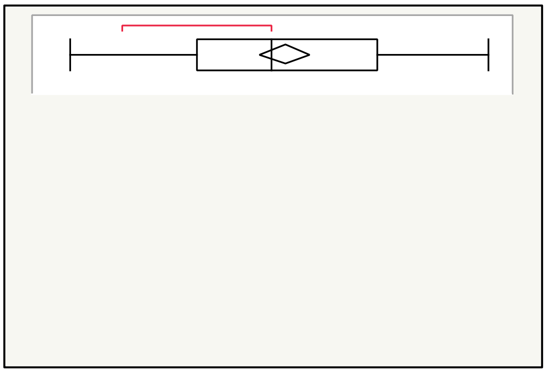


Figure 7.4 Distribution of Mathematics marks obtained by 2013 semester 2 respondents

Figure 7.5 and Figure 7.6 respectively show the frequency distribution of respondents' marks in English for the first and second semesters. The mean percentage for English obtained by first-semester respondents was 59.53%, with a standard deviation of 12.10; and for the second-semester respondents, it was 62.22%, with a standard deviation of 11.90. Supporting tables for both semesters are shown in Appendix D.2.3.

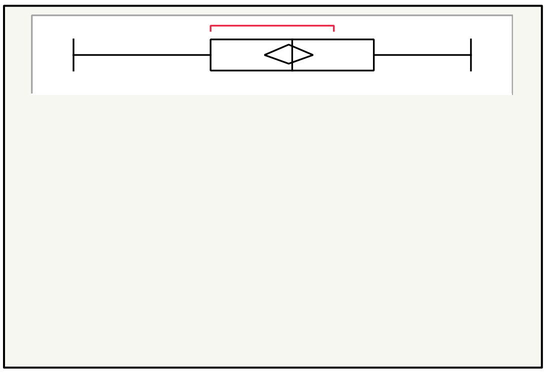


Figure 7.5 Distribution of English marks for 2013 semester 1 respondents

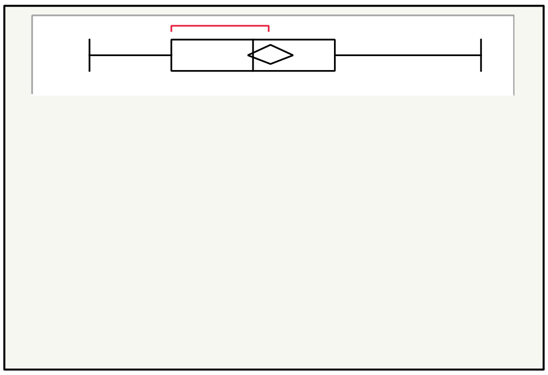


Figure 7.6 Distribution of English marks for 2013 semester 2 respondents

From the above statistics it is clear that most of the 2013 respondents did fairly well in Mathematics and English at school. To investigate the influence of the Mathematics and English marks of respondents on their final mark, these marks were included as part of their biographical profile score, as was done in the first implementation cycle.

7.3.4.2 Profile score

Similar to the first implementation cycle, a single summative biographical score per student based on the biographical properties below was calculated, namely –

- respondents' level of prior programming experience;
- their Grade 12 (matric) English level;
- their Grade 12 (matric) Mathematics level; and

- whether it was a first-time COS1511 registration or not (question 11).

This score is referred to as 'the profile score'.

The table of frequency distributions which follows serves to explain the profile score in more detail. Table 7.3 shows the frequency distributions for the respondents for both semesters in 2013.

Table 7.3 Frequency distributions of questions used to calculate profile scores of respondents for both semesters in 2013

	Semester 1		**Semester 2**	
Q10 Programming experience?	**N**	**% of Total**	**N**	**% of Total**
No experience (0 - None, Repeating COS1511 or registered for another programming module simultaneously)	23	42.59%	32	49.23%
Moderate (1 - IT at school, completed other programming course or have other programming experience)e	27	50.00%	25	38.46%
Experienced (2 - Employed as a programmer)	4	7.41%	8	12.31%
All	54	100.00%	65	100.00%
MATH >=60				
No	27	40.91%	29	38.16%
Yes	39	59.09%	47	61.84%
All	66	100.00%	76	100.00%
ENG >= 60				
No	28	42.42%	26	34.21%
Yes	38	57.58%	50	65.79%
All	66	100.00%	76	100.00%
Q11 FIRST time you have been registered for COS1511?				
No	6	10.91%	13	20.31%
Yes	49	89.09%	51	79.69%
All	55	100.00%	64	100.00%
Profile score				
0	0	0.00%	4	6.25%
1	10	18.52%	7	10.94%
2	14	25.93%	16	25.00%
3	10	18.52%	15	23.44%
4	18	33.33%	15	23.44%
5	2	3.70%	7	10.94%
All	54	100.00%	64	100.00%

Question 10 in the questionnaire (What experience do you have in ***programming***?) was used to identify respondents' prior programming experience, by providing the following options:

1. None
2. Computer Studies or Information Technology at school
3. Repeating COS1511
4. Currently enrolled for another programming module at Unisa
5. Did a programming course other than COS1511
6. Employed as a programmer
7. Other programming experience

Respondents who had no experience (option 1), who were repeating COS1511 (option 3) or were currently enrolled for another programming module at Unisa (option 4) were classified as having had no programming experience and received a score of 0. Respondents who did Computer Studies or Information Technology at school (option 2), who did a programming course other than COS1511 (option 5) or had other programming experience (option 7) were seen as having had some programming experience, and received a score of 1. Respondents who were employed as a programmer (option 6) were seen as having been experienced and received a score of 2. In the first semester, 43% of respondents had no experience while 7% were experienced. In the second semester, 49% had no experience, while 12% were experienced. In section 7.3.4.4 the unclassified responses to question 10 are discussed in more detail.

Mathematics and English marks for respondents as extracted from the Unisa student system were used to distinguish between respondents who obtained less than 60% (0); or 60% or more (1). Fifty-nine per cent of first semester respondents and 62% of second semester respondents obtained 60% or more in matric for Mathematics. Fifty-eight per cent of first semester respondents and 66% of second semester respondents obtained 60% or more for English.

Most of the first-semester respondents were registered for the first time for the module (89% of the first semester respondents and 80% of the second semester respondents). The majority of both first and second semester students obtained a profile score of between two and four (78% and 72% respectively).

Table 7.4 shows the profile scores with the corresponding average final marks (PM%) for both semesters. In the first semester no respondent had a profile score of 0. Four respondents had a profile score of 0 in the second semester and their mean final mark was 20%. In both semesters the mean final mark for respondents with a profile score of 1, was between 30% and 40% (38% for first-semester respondents and 32% for seven second-semester respondents). In both semesters the mean final mark for respondents with a profile score of 2, was between 40% and 50% (41% for first-semester respondents and 47% for seven second-semester respondents). First-semester respondents with a profile score of 3 had a mean final mark of 56%, while the second-semester respondents with a profile score of 3 had a mean final mark of 62%. In both semesters the mean final mark for respondents with a profile score of 4, was just short of a distinction (74% for first-semester respondents and 71% for seven second-semester respondents). In both semesters, the mean final mark for respondents who had a profile score of 5 was well above 80% (87% in the first semester and 85% in the second semester).

Table 7.4 Mean percentages: final mark (PM%) for profile scores for both semesters 2013

	Semester 1 PM%			Semester 2 PM%		
Profile score	**N**	**Mean**	**Std Dev**	**N**	**Mean**	**Std Dev**
0	0	0%	0	4	20.2%	5.90
1	10	38.2%	19.0	7	32.1%	16.3
2	14	40.5%	25.9	16	46.6%	24.7
3	10	55.9%	30.9	15	62.3%	18.9
4	18	74.2%	19.2	15	70.9%	17.1
5	2	86.7%	4.72	7	84.6%	9.95
All	54	55.9%	27.9	64	57.2%	25.4

The overall mean for the final mark (PM%) for the first semester was 56%, while the overall mean for the final mark for the second semester was 57%. Although the number of responses were too small to allow generalisation or to assume that it may hold for the 2013 COS1511 population, it is clear that a higher profile score corresponded with a higher final mark, as was found in the first implementation cycle.

7.3.4.3 The manner of tutorial use (questions 13 to 15, and 20 to 22)

The manner of tutorial use was used to investigate six aspects of using the tutorial, namely whether respondents –

- used the tutorial while working through the Study Guide (question 13);
- watched the updated Instructions (question 14);
- thought watching the Instructions helped them to use the tutorial (question 15);
- used the tutorial before or while completing Assignment 1 (question 20);
- continued to use the tutorial after submitting Assignment 1 (question 21); and
- the time spent using the tutorial (question 22).

In Table 7.5 the responses to the questions investigating the manner in which respondents used the tutorial are shown for both semesters.

The majority of the respondents indicated that they used the tutorial while working through the Study Guide[17] (74% in the first semester and 59% in the second semester). Most of the respondents watched the Instructions on how to use the tutorial (76% of first-semester respondents and 61% of second-semester respondents). Two-thirds of the first-semester respondents believed that watching the Instructions helped them to some extent or definitely, to use the tutorial (66%) while just more than half of second-semester respondents felt the same (52%). Only 18% of first-semester respondents thought that the instructions did not help them at all or not really, while 22% of second-semester respondents held the same view. Sixteen per cent of first-semester respondents and 26% of second-semester respondents were undecided on this matter.

[17] COS1511 students use a Study Guide instead of a prescribed text book (Halland, 2011).

Table 7.5 Tutorial use by respondents in both semesters of 2013

	First semester		Second semester	
	N	% of Total	N	% of Total
Q13 Do you use the Drawing Variable Diagrams tutorial for this module while working through the study guide?				
Yes	42	73.68%	38	59.38%
No	15	26.32%	26	40.63%
All	57	100.00%	64	100.00%
Q14 Did you watch the Instructions to learn how to use the Drawing Variable Diagrams tutorial?				
Yes	37	75.51%	35	61.40%
No	12	24.49%	22	38.60%
All	49	100.00%	57	100.00%
Q15 Did watching the Instructions to learn how to use the Drawing Variable Diagrams tutorial, help you?				
Not at all	3	6.82%	6	12.00%
Not really	5	11.36%	5	10.00%
Undecided/Neutral	7	15.91%	13	26.00%
To some extent	21	47.73%	17	34.00%
Definitely	8	18.18%	9	18.00%
All	44	100.00%	50	100.00%
Q20 Did you use the Drawing Variable Diagrams tutorial before or while completing Assignment 1?				
Yes	32	57.14%	29	46.03%
No	24	42.86%	34	53.97%
All	56	100.00%	63	100.00%
Q21 Did you use the Drawing Variable Diagrams tutorial after you have submitted Assignment 1?				
Yes	11	20.00%	29	45.31%
No	44	80.00%	35	54.69%
All	55	100.00%	64	100.00%
Q22 Up to now, how much time in total, have you spent using the Drawing Variable Diagrams tutorial?				
Less than 1 hour	18	31.58%	30	47.62%
1 to 10 hours	31	54.39%	29	46.03%
11 to 20 hours	4	7.02%	3	4.76%
20 to 30 hours	3	5.26%	0	0.00%
More than 30 hours	1	1.75%	1	1.59%
All	57	100.00%	63	100.00%

Most of the first-semester respondents used the tutorial before or while completing Assignment 1 (57%), while in contrast, most of the second-semester respondents did *not* use the tutorial before or while completing Assignment 1 (54%). However, while only 20% of the first-semester respondents continued using the tutorial after submitting Assignment 1, all of the second-semester respondents who used the tutorial before or while completing Assignment 1 continued doing so (45%).

By the time respondents completed the questionnaires they should have studied all the lessons in the Study Guide as well as all the activities in the tutorial. Approximately one third of first-semester respondents (32%) and nearly half (48%) of second-semester respondents, had used the tutorial for less than an hour, while 54% of first-semester respondents and 46% of second-semester respondents had used it for up to 10 hours. Only 14% of first-semester respondents and 6% of second-semester respondents had used it for longer than 10 hours.

7.3.4.4 Students' prior experience of programming and use of tracing (questions 10, 12, 16 and 17)

In Table 7.6 the frequency distribution of questionnaire items for respondents for both semesters in 2013 are shown in relation to –

- programming experience (question 10);
- drawing variable diagrams before enrolling for COS1511 (question 12);
- drawing variable diagrams to understand programs in the Study Guide (question 16); and
- drawing variable diagrams to debug their programs (question 17).

As mentioned before, the responses to question 10 were collapsed into three possibilities, that is, no experience, moderate and experienced, for the purpose of the profile score (see section 7.3.4.2). Here the unclassified responses are reported. Note that the number of responses to option 2 in question 10 (repeating COS1511), differs from the number reported for question 11 in Table 7.3, where there were only two options (first time registered for COS1511 or not). In both semesters, approximately a third of respondents had no prior programming experience at all (31% in the first semester and 37% in the second semester). Fifteen per cent and 17% respectively had Computer Applications or Information Technology at school. Four per cent of first-semester respondents and 11% of second-semester respondents were repeating COS1511. In the first semester, 7% of respondents were also enrolled for another programming module, while 2% of second-semester respondents were enrolled for another programming module at the same time. Twenty per cent of first-semester respondents and 9% of second-semester respondents had completed another programming course. Seven per cent of first-semester respondents and 12% of second-semester respondents were employed as programmers, while 15% of first-semester respondents and 12% of second-semester respondents had other programming experience.

The majority of respondents had never drawn variable diagrams before (79% in the first semester and 91% in the second semester) and claimed to draw variable diagrams to assist them in understanding programs in the Study Guide (65% in the first semester and 72% in the second semester). Most of the first-semester respondents drew variable diagrams to help them debug their programs (67%), while most of the second-semester respondents (64%) did *not* do so.

Table 7.6 Frequency distribution of questionnaire items for students' prior experience of programming and use of tracing for both semesters in 2013

	Semester 1		Semester 2	
Q10 What experience do you have in programming?	**N**	**% of Total**	**N**	**% of Total**
None	17	31.48%	24	36.92%
Computer Studies or Information Technology at school	8	14.81%	11	16.92%
Repeating COS1511	2	3.70%	7	10.77%
Currently enrolled for another programming module at Unisa	4	7.41%	1	1.54%
Did a programming course other than COS1511	11	20.37%	6	9.23%
Employed as a programmer	4	7.41%	8	12.31%
Other programming experience	8	14.81%	8	12.31%
All	54	100.00%	65	100.00%
Q12 Have you drawn variable diagrams before enrolling for COS1511?				
Yes	12	21.05%	6	9.23%
No	45	78.95%	59	90.77%
All	57	100.00%	65	100.00%
Q13 Do you use the Drawing Variable Diagrams tutorial for this module while working through the study guide?				
Yes	42	73.68%	38	59.38%
No	15	26.32%	26	40.63%
All	57	100.00%	64	100.00%
Q16 Do you draw your own variable diagrams to help you to understand programs in the study guide?				
Yes	45	78.95%	36	55.38%
No	12	21.05%	29	44.62%
All	57	100.00%	65	100.00%
Q17 Do you draw your own variable diagrams to debug your programs?				
Yes	38	66.67%	23	35.38%
No	19	33.33%	42	64.62%
All	57	100.00%	65	100.00%
Q22 Up to now, how much time in total, have you spent using the Drawing Variable Diagrams tutorial?				
Less than 1 hour	18	31.58%	30	47.62%
1 to 10 hours	31	54.39%	29	46.03%
11 to 20 hours	4	7.02%	3	4.76%
20 to 30 hours	3	5.26%	0	0.00%
More than 30 hours	1	1.75%	1	1.59%
All	57	100.00%	63	100.00%

7.3.4.5 Learning from the tutorial (questions 18, 19, 23 to 36, 42 and 43)

A single set of response ratings was calculated to represent a combined measure of respondents' perception of how much they learned from the tutorial.

The questionnaire items investigated in questions 18, 19, 23 to 36, 42 and 43 as listed in Tables 7.9 and 7.10 were used to describe the joint construct of respondents' 'learning experience of the Drawing Variable Diagrams Tutorial'. The frequency distributions of the calculated 'learning experience' scores are also presented in Tables 7.7 and 7.8. In both tables the rating scale classes have been condensed to three rating categories. Table 7.7 describes the joint construct of 'learning experience of the Drawing Variable Diagrams Tutorial' for the first semester in 2013, while Table 7.8 describes it

Table 7.7 Frequency distributions of respondents' 'learning experience of the Drawing Variable Diagrams Tutorial' semester 1 2013

	Not at all - Not really		Undecided - Neutral		To some extent - Definitely		All	
	N	% of Total	N	% of Total	N	% of Total	N	% of Total
Q18 Do you feel that using variable diagrams improves your programming skills?	6	10.53%	12	21.05%	39	68.42%	57	100.00%
Q19 Do you feel that using variable diagrams assist with understanding the flow of logic in a program?	4	7.02%	7	12.28%	46	80.70%	57	100.00%
Q23 Did watching the Drawing Variable Diagrams tutorial, help you to understand `if` statements?	12	21.43%	14	25.00%	40	53.57%	56	100.00%
Q24 Did watching the Drawing Variable Diagrams tutorial, help you to understand `while` loops?	12	21.43%	14	25.00%	30	53.57%	56	100.00%
Q25 Did watching the Drawing Variable Diagrams tutorial, help you to understand nested `if` statements?	11	20.37%	15	27.78%	28	51.85%	54	100.00%
Q26 Did watching the Drawing Variable Diagrams tutorial, help you to understand `switch` statements?	12	21.82%	14	25.45%	29	52.73%	55	100.00%
Q27 Did watching the Drawing Variable Diagrams tutorial, help you to understand the difference between `while` loops and `do` .. `while` loops?	11	20.37%	17	31.48%	26	48.15%	54	100.00%
Q28 Did watching the Drawing Variable Diagrams tutorial, help you to understand what happens when a function is executed?	10	18.18%	13	23.64%	32	58.18%	55	100.00%
Q29 Did watching the Drawing Variable Diagrams tutorial, help you to understand value parameters?	13	23.64%	14	25.45%	28	50.91%	55	100.00%
Q30 Did watching the Drawing Variable Diagrams tutorial, help you to understand reference parameters?	10	18.18%	15	27.27%	30	54.55%	55	100.00%
Q31 Did watching the Drawing Variable Diagrams tutorial, help you to understand the difference between value and reference parameters?	12	21.82%	15	27.27%	28	50.91%	55	100.00%
Q32 Did watching the Drawing Variable Diagrams tutorial, help you to understand one-dimensional arrays?	14	25.45%	17	30.91%	24	43.64%	55	100.00%
Q33 Did watching the Drawing Variable Diagrams tutorial, help you to understand two-dimensional arrays?	15	27.27%	16	29.09%	24	43.64%	55	100.00%
Q34 Did watching the Drawing Variable Diagrams tutorial, help you to understand strings?	11	20.00%	14	25.45%	30	53.55%	55	100.00%
Q35 Did watching the Drawing Variable Diagrams tutorial, help you to understand structs?	16	29.09%	19	34.55%	20	36.36%	55	100.00%
Q36 To trace a program means to form a mental picture of what the program does and how it is done. To what degree did the Drawing Variable Diagrams tutorial assist you to master tracing?	9	16.36%	16	29.09%	30	54.55%	55	100.00%
Q42 Did you find that the Drawing Variable Diagrams tutorial is directly applicable to the programming assignments in the course?	6	10.71%	12	21.43%	38	67.86%	56	100.00%
Q43 Do you think that you will apply the general concept of variable diagrams in future programming projects?	6	10.91%	2	3.64%	48	85.45%	55	100.00%

for the second semester. Note that question 17 (To what degree did the tutorial assist you to master tracing?) in the questionnaires used in the first implementation cycle was removed from the user experience (described in section 7.3.4.6) and included as part of the 'learning experience' of respondents. In the questionnaires used in the second implementation cycle, question 17 was numbered question 36.

Table 7.8 Frequency distributions of respondents' 'learning experience of the Drawing Variable Diagrams Tutorial' semester 2 2013

	Not at all - Not really		**Undecided - Neutral**		**To some extend - Definitely**		**All**	
	N	**% of Total**	**N**	**% of Total**	**N**	**% of Total**	**N**	% of Total
Q18 Do you feel that using variable diagrams improves your programming skills?	18	28.13%	10	15.63%	36	56.25%	64	100.00%
Q19 Do you feel that using variable diagrams assist with understanding the flow of logic in a program?	9	14.06%	16	25.00%	39	60.94%	64	100.00%
Q23 Did watching the Drawing Variable Diagrams tutorial helps you understand `if` statements	26	42.62%	5	8.20%	30	49.18%	61	100.00%
Q24 Did watching the Drawing Variable Diagrams tutorial, help you to understand `while` statements?	26	43.33%	6	10.00%	28	46.67%	60	100.00%
Q25 Did watching the Drawing Variable Diagrams tutorial, help you to understand nested `if` statements?	28	47.46%	7	11.86%	24	40.68%	59	100.00%
Q26 Did watching the Drawing Variable Diagrams tutorial, help you to understand `switch` statements?	27	46.56%	6	10.34%	25	43.10%	58	100.00%
Q27 Did watching the Drawing Variable Diagrams tutorial, help you to understand the difference between `while` loops and `do` .. `while` loops?	28	47.45%	7	11.86%	24	40.68%	59	100.00%
Q28 Did watching the Drawing Variable Diagrams tutorial, help you to understand what happens when a function is executed?	20	33.90%	14	23.73%	25	42.37%	59	100.00%
Q29 Did watching the Drawing Variable Diagrams tutorial, help you to understand value parameters?	21	37.50%	10	17.86%	25	44.64%	56	100.00%
Q30 Did watching the Drawing Variable Diagrams tutorial, help you to understand reference parameters?	28	48.28%	8	13.79%	26	44.83%	58	100.00%
Q31 Did watching the Drawing Variable Diagrams tutorial, help you to understand the difference between value and reference parameters?	25	43.10%	9	15.52%	24	41.38%	58	100.00%
Q32 Did watching the Drawing Variable Diagrams tutorial, help you to understand one-dimensional arrays?	29	50.87%	8	14.04%	20	35.09%	57	100.00%
Q33 Did watching the Drawing Variable Diagrams tutorial, help you to understand two-dimensional arrays?	32	54.23%	9	15.25%	18	30.51%	59	100.00%
Q34 Did watching the Drawing Variable Diagrams tutorial, help you to understand strings?	30	50.85%	9	15.25%	20	33.90%	59	100.00%
Q35 Did watching the Drawing Variable Diagrams tutorial, help you to understand structs?	30	52.63%	3	5.26%	24	42.11%	57	100.00%
Q36 To trace a program means to form a mental picture of what the program does and how it is done. To what degree did the Drawing Variable Diagrams tutorial assist you to master tracing?	21	35.59%	10	16.95%	28	47.46%	59	100.00%
Q42 Did you find that the Drawing Variable Diagrams tutorial is directly applicable to the programming assignments in the course?	13	22.54%	20	33.90%	26	44.07%	59	100.00%
Q43 Do you think that you will apply the general concept of variable diagrams in future programming projects?	18	30.51%	21	35.59%	20	33.90%	59	100.00%

The item analysis for learning experience for both semesters showed Cronbach's coefficient alphas of above 0.96, confirming the reliability of the questions (Terre Blanche et al., 2006), as can be seen in Table 7.9. Supporting tables are shown in Appendix D.2.4.

Table 7.9 Cronbach's coefficient alphas for learning experience for both semesters in 2013

Semester	**Cronbach's coefficient alpha**
Semester 1 2013	0.9640
Semester 2 2013	0.9679

Since internal consistency reliability was established a single 'learning experience' score could be calculated to represent the separate questionnaire items, although the small sample size remains problematic.

In the *first semester* the ratings for all the questions reflected that the majority of respondents felt that the tutorial assisted them to some extent or definitely in all aspects covered by the questions in the 'learning experience' construct. In particular, a large proportion believed that they would apply the concept of variable diagrams in future (85%) and felt using variable diagrams both improved their programming skills (68%) and assisted with understanding the flow of logic in a program (81%). Sixty-eight per cent found the tutorial applicable to the programming assignments in the course, while 55% believed it helped them to master tracing. Between 50% and 58% of respondents rated the tutorial to assist them in understanding all programming concepts and constructs covered in the tutorial (`if`, nested `if` and `switch` statements; `while` loops; what happens when a function is executed; value and reference parameters and the difference between them; and strings) to some extent or definitely. Fewer respondents believed that the tutorial assisted them in understanding one- and two dimensional arrays (44% in both cases), structs (36%) and the difference between `while` and `do..while` loops (48%).

In the *second semester* the respondents were less positive about their learning experience from using the tutorial. Only 34% indicated that they would apply the concept of variable diagrams in future.

While 56% believed using variable diagrams improved their programming skills and 61% felt that using variable diagrams assisted with understanding the flow of logic in a program, only 47% of respondents believed the tutorial helped them to master tracing and 44% found it applicable to the programming assignments in the course. The ratings from second-semester respondents indicated that the tutorial only assisted them in understanding the `if` and `while` statements; what happens when a function is executed and understanding value parameters. In these cases the percentage ratings for 'To some extent' or 'Definitely' were larger than those for 'Not at all' or 'Not really'. For all the other programming constructs and concepts covered by the tutorial the percentage of respondents who rated it to assist them 'Not at all' or 'Not really' were larger than the percentage who rated it to assist them 'To some extent' or 'Definitely'.

The learning experience score for a student was calculated as the average of the ratings of all eighteen questions, which can range from 0 to 5. A score of 4 on the learning experience for example, indicates that the average rating a student gave to the questions was ‘To some extent’ and a score of 5 as ‘Definitely’, which reflects a very positive learning experience. The mean learning experience score for the first-semester respondents came to 3.54 when it was calculated and for the second-semester respondents it came to 3.22. These mean scores indicate that respondents in both semesters gave their

learning experience of the tutorial a rating of between ‘Neutral/Undecided’ and ‘To some extent’ and that second-semester respondents rated it somewhat lower than first-semester respondents. Supporting tables for both semesters are shown in Appendix D.2.4.

Figure 7.7 and Figure 7.8 show the frequency distributions of the learning experience scores of respondents for the first and second semesters in 2013 respectively.

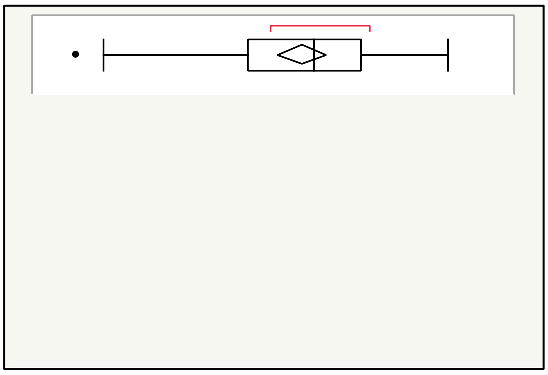


Figure 7.7 Distribution of learning experience scores for 2013 semester 1 respondents

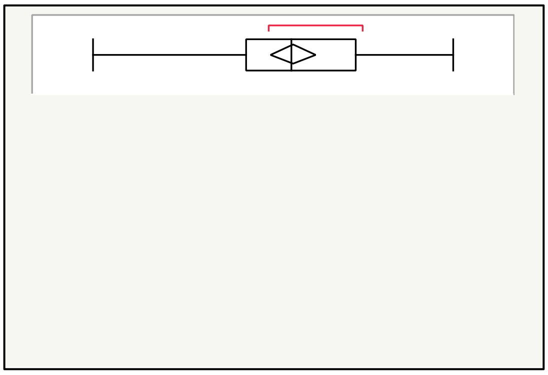


Figure 7.8 Distribution of learning experience scores for 2013 semester 2 respondents

7.3.4.6 Positive user experience (questions 37 to 41)

As in the first implementation cycle, a single set of response ratings – representing a combined measure of respondents’ user experience – was used to represent respondents’ user experience.

The questionnaire items investigated in questions 37 to 41 as listed in Tables 7.10 and 7.11 were used to describe the joint construct of ‘positive user experience of the Drawing Variable Diagrams Tutorial usage’. The frequency distribution of the calculated ‘positive user experience’ scores are also presented in Tables 7.10 and 7.11. The rating scale classes have been condensed to three rating categories in both tables. Table 7.10 describes the joint construct of ‘positive user experience of the Drawing Variable Diagrams Tutorial usage’ for the first semester in 2013, while Table 7.11 describes it for the second semester. Note that question 36 (To what degree did the tutorial assist you to master tracing?) included in the joint construct of ‘positive user experience of the Drawing Variable Diagrams Tutorial usage for the first implementation cycle, was replaced with Question 41 (Did you find the tutorial easy to use?) for the second implementation cycle.

Table 7.10 User experience response ratings representing positive user experience of the Drawing Variable Diagrams Tutorial usage for semester 1 2013 (all respondents)

	Not at all – not really		**Neutral**		**Some extent – definitely**		**All**	
	N	**% of Total**	**N**	**% of Total**	**N**	**% of Total**	**N**	**% of Total**
Q37 Did you find it interesting to use the tutorial?	10	18.18%	10	18.18%	35	63.64%	55	100.00%
Q38 Did you find it motivating to use the tutorial?	11	20.37%	10	18.52%	33	61.11%	54	100.00%
Q39 Did you enjoy using the tutorial?	10	18.18%	11	20.00%	34	61.82%	55	100.00%
Q40 Did you find it frustrating to use the tutorial? *	14	25.45%	13	23.64%	28	50.91%	55	100.00%
Q41 Did you find the tutorial easy to use?	8	14.29%	14	25.00%	34	60.71%	56	100.00%

Legend: * - Question 40 was inverted because it was negative.

Table 7.11 User experience response ratings representing positive user experience of the Drawing Variable Diagrams Tutorial usage for semester 2 2013 (all respondents)

	Not at all – not really		**Neutral**		**Some extent – definitely**		**All**	
	N	**% of Total**	**N**	**% of Total**	**N**	**% of Total**	**N**	**% of Total**
Q37 Did you find it interesting to use the tutorial?	15	26.32%	12	21.05%	30	52.63%	57	100.00%
Q38 Did you find it motivating to use the tutorial?	21	35.59%	14	23.73%	24	40.68%	59	100.00%
Q39 Did you enjoy using the tutorial?	16	27.59%	14	24.13%	28	48.28%	58	100.00%
Q40 Did you find it frustrating to use the tutorial? *	21	31.67%	12	20.00%	29	48.33%	60	100.00%
Q41 Did you find the tutorial easy to use?	12	20.34%	15	25.42%	32	54.24%	59	100.00%

Legend: * - Question 40 was inverted because it was negative.

The item analysis for positive user experience for both semesters showed Cronbach’s coefficient alphas[18] of above 0.82, confirming the reliability of the questions (Terre Blanche et al., 2006), as can be seen in Table 7.12. Supporting tables are shown in Appendix D.2.5.

Table 7.12 Cronbach’s coefficient alphas for positive user experience for both semesters in 2013

Semester	**Cronbach’s coefficient alpha**
Semester 1 2013	0.8542
Semester 2 2013	0.8229

Since internal consistency reliability was established a ‘positive user experience’ score could be calculated to represent the five separate questionnaire items. However, the small sample size remains

[18] Cronbach’s coefficient alpha is the most common estimate of internal consistency, which is the degree to which each item in a scale correlates with each other. An alpha value of 0.75 is considered to indicate reliable internal consistency (Terre Blanche et al., 2006).

problematic. Question 40 (Did you find it frustrating to use the tutorial?) was negative and therefore inverted.

The first semester respondents experienced using the tutorial more positively than second-semester respondents. Most first-semester respondents found the tutorial to some extent or definitely interesting to use (64%), while just more than half of second-semester respondents felt the same (53%). Likewise, most first-semester respondents found it motivating (61%) while 41% of second-semester respondents thought so. More first-semester respondents (61%) than second-semester respondents (48%) enjoyed using the tutorial. Only 25% of the first-semester respondents found the tutorial frustrating to use while 32% of the second-semester found it frustrating to use. Sixty-one per cent of first-semester respondents and 54% of second-semester respondents found the tutorial easy to use.

Similar to the first implementation cycle, the positive user experience score for a student was calculated as the average of the ratings of all five questions, which can range from 0 to 5. A score of 4 on the user experience for example indicates that a student answered four of the questions with a rating of ‘to some extent’ or ‘definitely’, which reflects a very positive user experience. The mean positive user experience score for the first-semester respondents came to 3.56 when it was calculated and for the second-semester respondents it came to 3.26. These mean scores indicate that respondents had a positive user experience of the tutorial, indicating a rating between ‘Neutral/Undecided’ and ‘To some extent’. Supporting tables for both semesters are shown in Appendix D.2.5.

Note that some students did not use the tutorial for a long time (less than 1 hour), or did not need the tutorial, but might have perused it, and therefore may have indicated their impression, even if they had not used it. The user experience was therefore calculated for all respondents who have answered questions 37 to 41.

Figure 7.9 and Figure 7.10 show the frequency distributions for the user experience of respondents for the first and second semesters in 2013 respectively.

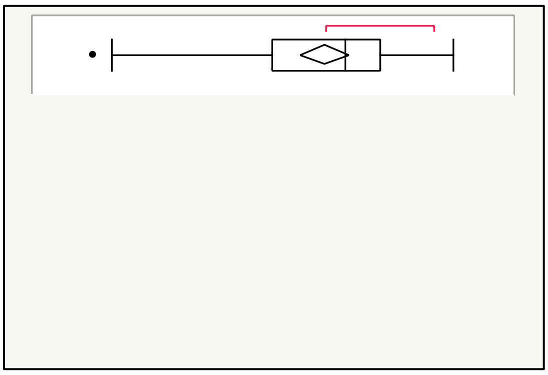


Figure 7.9 Distribution of Positive user experience for 2013 semester 1 respondents

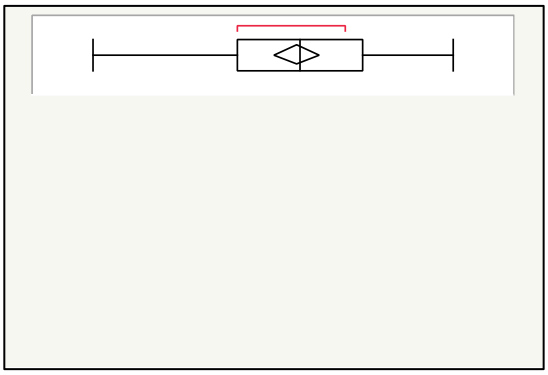


Figure 7.10 Distribution of Positive user experience for 2013 semester 2 respondents

In the next section a summary of the factors that could possibly have affected a student’s final mark is discussed.

Following the above exposition about factors affecting the final marks, the factors affecting the final marks of the respondents can be summarised as follows:

- Note that due to the small number of responses, none of the descriptive statistics can be generalised to the 2013 COS1511 population. Nevertheless, some of the descriptive statistics confirm the modelling done in the first implementation cycle.
- Most of the respondents for both semesters did fairly well in Mathematics and English in matric, with averages of 60% to 62% respectively. This in turn had a positive effect on their profile scores, with the majority achieving a profile score of between 2 and 4. Although the numbers of responses for the two semesters were too small to hold for the population, a higher profile score were clearly associated with a higher final mark. Similar to the first implementation cycle, only respondents who were employed as programmers could achieve a profile score of 5. In both semesters the average final mark for respondents with a profile score of 5 was a distinction. The average final mark for respondents with a profile score of 4, indicating a moderate level of programming experience (having done Computer Studies or Information Technology at school or a programming course other than COS1511, or having other programming experience) was 74% and 71% respectively for the two semesters. This confirms that previous programming experience was an important factor in students’ final mark.
- The majority of respondents in both semesters watched the updated Instructions on how to use the tutorial. Two-thirds of first-semester respondents believed it helped them while approximately half of second-semester respondents agreed. Although more of the first-semester respondents used the tutorial in completing Assignment 1, only 20% of them continued using the tutorial afterwards. In contrast, while most of the second-semester respondents did not use the tutorial in completing Assignment 1, those who did so continued using the tutorial afterwards.
- The time spent on using the tutorial was lower than expected, with most respondents spending only between 0 and 10 hours using it. The fact that the majority did not use the tutorial after submitting Assignment 1, may explain this. While respondents with no programming experience comprised the largest proportion of students in both semesters, a bigger proportion of first-semester respondents than second-semester respondents had used variable diagrams before. A larger proportion of first-semester respondents than second-semester respondents also drew variable diagrams to understand programs in the Study Guide and to debug their programs.

- The learning experience score for both semesters indicated a rating of between 'Neutral/Undecided' and 'To some extent', with a slightly higher score for first-semester respondents. More first-semester respondents also believed that using variable diagrams improved their programming skills and assisted in understanding the flow of logic in a program. Correspondingly more of them indicated that they would apply variable diagrams in future. This tie in with the fact that more of them drew variable diagrams to understand and debug programs, confirming the value of tracing. The fact that most of the respondents did not continue using the tutorial after they had submitted Assignment 1, may be one of the reasons why they did not rate their learning experience from the tutorial higher. Assignment 1 covered only the first eleven of the 21 activities in the tutorial. Students who did not continue using the tutorial after submitting Assignment 1, would not have studied the activities on `for` loops; executing functions, value and reference parameters, one- and two dimensional arrays, strings and structs.
- Similar to the learning experience scores, the positive user experience scores for both semesters indicated a rating of between 'Neutral/Undecided' and 'To some extent', again with a slightly higher score for first-semester respondents. This may also be related to the fact that most of the respondents did not continue using the tutorial after they had submitted Assignment 1.

In the next section the quantitative investigation for the second implementation cycle, where participants' use of the tutorial was observed, is discussed. The feedback on the COS1511 discussion forum from students on how they experienced using the tutorial during the second implementation cycle is also covered as part of the quantitative investigation.

7.4 Direct live observation and eye tracking in the HCI laboratory

During the second implementation cycle, the same procedure was followed as during the first implementation cycle, to observe and track students' eye movements while they used the Drawing Variable Diagrams Tutorial as described in section 6.4.1, though at an earlier stage. In the first implementation cycle the observations in the HCI laboratory were done during the fourth and fifth week of the second semester in 2012, and in the second implementation cycle it was repeated in the week preceding commencement of the second semester in 2013. The direct live observation and eye tracking in the HCI laboratory during the second implementation cycle are presented below, in terms of the participants concerned, an analysis of gaze replays and an analysis of the questionnaire completed after eye tracking.

7.4.1 Participants

Seven participants volunteered, comprising of one female and six males. The ages of the participants varied between 19 and 31 years. The participants spoke four different home languages. Five of them were registered for COS1511 for the first time. One of the remaining participants was repeating COS1511 for the fifth time, while the other one did not progress to write the examination during his previous registration. All claimed to be computer-literate.

One participant was registered for the NDEEN one for BSc Computing; two for BSc and two for the extended programs. Of the latter, one was registered for the degree and the other for the diploma. Students on the extended program for the degree or diploma, study an additional year, as in this case all first year subjects are offered over a year instead of over a semester as in the normal program. Three participants had never drawn variable diagrams before. Six of the participants indicated that they had not used the used the Drawing Variable Diagrams Tutorial before the observations. The participant who had used the tutorial before was repeating COS1511 for the fifth time, but had only received his study material a week before the observations. If he had used the tutorial before, it was probably the previous version of it. Three participants passed the examination at the end of the semester, three failed and one did not write the examination. Table 7.13 provides a summary of the biographical information of the participants. As in the first implementation cycle, feedback was obtained from the open-ended post-test questionnaire participants completed while background was acquired from the Unisa student system and/or conversations with the participants.

Table 7.13 Biographical information of participants observed in HCI laboratory

Participant	**Age**	**Gender**	**First language**	**Qualification registered for**	**No of times registered for COS1511**	**Drawn variable diagrams before**	**Used tutorial before**	**Exam results**
1	31	male	Xhosa	BA Comm*	1	no	no	30%
2	19	male	English	BSc Computing	1	no	no	58%
3	25	male	English	Extended program for degree***	1	yes	no	19%
4	26	female	Afrikaans	BSc	1	yes	no	92%
5	28	male	Twana	NDEEN **	5	yes	no	n/a
6	20	male	English	Extended program for diploma ***	2	no	yes	14%
7	23	male	Afrikaans	BSc	1	yes	no	89%

(Legend: * BA Comm – BA Communication Science **NDEEN – National Diploma in Electrical Engineering; * Extended program – Students on the extended program for degree or diploma study an additional year as all first year subjects are offered over a year instead of a semester as in the normal program**

7.4.2 Analysis of gaze replays

Similar to the first implementation cycle, gaze replays and observation were used to establish how participants experienced the usability of the Drawing Variable Diagrams Tutorial after it had been modified for the second implementation[19]. The analysis is discussed based on the same issues that were identified during the observations and gaze replays in the first implementation cycle, namely learning from the tutorial, the instructions on how to use the tutorial, navigation through the tutorial, and reading skills.

7.4.2.1 Learning from the tutorial

Recall from section 6.4.3.1, that in order to learn from the tutorial it was expected that students would first study the program code in the Program Code box to form an idea of the purpose of the program, then read the highlighted program statement again and study the explanation in the Explanation box to make sure they understand the statement. Thereafter, they were expected to inspect the Memory box to see how the variable diagrams for the statement are drawn (if any) and to look at the Console Window to inspect the output (if any) produced or to examine the input given to the program. To continue to the next statement in the program, students should have clicked on the *Next* button, and to return to the previous statement, on the *Back* button.

Students' ability to draw variable diagrams after working through the tutorial as well as the difference in the variable diagrams they drew in the pre-test and retrospective comprehension tests in combination with their behaviour while working through the tutorial, were used to judge whether they learned from working through the tutorial or not. As in the first implementation cycle, this was a very artificial situation requiring participants to work through more than would typically be done during one session in their own time. In addition, the observations and eye tracking were done at an earlier stage than in the first implementation cycle. A brief description of participants' behaviour as related to their learning experience follows below.

Participant 1 did not draw any variable diagrams, presumably because he did not work through the lessons Study Guide before, as requested. He probably did not understand or know enough C++ to be able to trace after only working through the tutorial. The variable diagrams drawn by participants 2, 4, 5 and 7 for both the pre-test and the retrospective comprehension tests, were all correct. This could be because the self-sampling students who volunteered for this cycle were better prepared for the module than those in the first cycle. Evidence of this may be the fact that participants 2, 4 and 5 all picked up an error in activity 9.a.v, namely that the loop stops at 15 instead of 20 as indicated in the program (a mistake that crept in while the tutorial was adapted for the second implementation cycle). However, some evidence of learning was displayed by participants 3 and 6, as can be seen from the variable

[19] The data collection has been described in section 4.3.5.3. This section explains how eye tracking is done and how it works, the form of data collection in eye tracking and how gaze replays are analysed.

diagrams they drew during the retrospective comprehension test. The variable diagrams participant 3 drew for activity 4.b were correct, but the pre-test and retrospective comprehension test variable diagrams he drew were incorrect, since he did not realise that variables kept their values when a loop is executed. For each execution of the loop and the corresponding input value, he drew the variable diagrams as if the variables had not been assigned any values yet. He indicated that he struggled with the looping and "find it easier to draw it on paper then to draw it on the actual program because it is easier to identify variable and their values", so he may have missed the purpose of the tutorial. Participant 6 did not draw variable diagrams for the pre-test. While drawing the variable diagrams for both activity 4.b and the retrospective comprehension test (program 2), he used the tutorial. His variable diagrams were not quite correct, as he copied the program code and attempted to draw variable diagrams next to the relevant lines of code. In activity 4.b, he made a subtraction error and in program 2 he did not trace the loop. Participant 5 also used the tutorial while doing the exercise at the end of activity 4.b. Participants 2 and 6 used the desktop calculator to do or check calculations.

In summary, this indicates a better learning experience than in the first implementation cycle, where there was no difference between the pre-test and retrospective comprehension test results for any of the three participants who drew variable diagrams. In this cycle some of the participants who could not draw variable diagrams in their pre-test comprehension tests, used the tutorial to draw correct variable diagrams for activity 4.b. This did not happen during the qualitative investigation in the first cycle. Apparently the changes made to update the tutorial improved students' learning experience while using it.

7.4.2.2 Problems/issues with the instructions on how to use the tutorial

As described in section 6.4.5, the instructions for using the Drawing Variable Diagrams Tutorial were updated extensively to explain what a variable and a variable diagrams is; the purpose of variable diagrams and the tutorial; the relationship between the activities in the tutorial and the study guide; how to use the tutorial including a walk-through of activity 3.a showing how to reconcile the boxes; and some notes on how to proceed at the end of an activity (See the updated instructions in Appendix C). The user's attention was also drawn to the instructions by placing a button 'How to use this tutorial' immediately below the introductory explanation on the introductory frame (landing page), in addition to the *Instructions* button on top of the landing page.

The updated instructions seemed to suffice, since all participants were able to use the tutorial as intended once they had read the instructions. All participants read the instructions, using an average time of 12 minutes and 21 seconds to do so. The time spent reading the instructions varied from 4 minutes and 11 seconds to 25 minutes.

The following behaviour of participants confirms that the updated instructions suffice. All participants made an effort to reconcile the four boxes in order to understand the activities, although not always with the same level of success. Participant 1 made notes from the instructions on what a variable diagram is, and the layout of the tutorial. Participants 3 and 5 did not study the instructions before attempting the activities, but once they realised that they did not know how to proceed, returned to the instructions and thereafter experienced no problems in using the tutorial. Participant 6 did not read all the instructions before proceeding to the activities, but soon realised that he needed to do so and thereafter returned to it several times.

7.4.2.3 Navigation through the tutorial

In the eye tracking and observations in the first implementation cycle, five problems areas with navigating through the tutorial were identified, namely general navigation problems, using the *Next* button, using the *Back* button, how to continue at the end of an activity and attempts to provide input. To address these problems, the *Next* and *Back* buttons were made more prominent by giving them an outline and writing 'Next' and 'Back' inside the buttons themselves; a *Finished* button replaced the *Next* button at the end of an activity with a prompt in the Explanation box to instruct users to use the *Index* button to return to the list of activities; and an explicit explanation that users need not provide any input was put in the explanations at the beginning of activity 3.a as well as in the instructions.

General navigation problems in the first implementation cycle included clicking repeatedly in different places on the screen when a participant did not know how to proceed; right-clicking in search of a pop-up menu and trying to use the buttons in the screen prints in the instructions to choose an activity. Only two similar cases transpired in the eye tracking and observations in the second implementation cycle, namely one participant who clicked repeatedly in the Memory box and another who sometimes clicked inside some boxes. The latter also sometimes selected text, which might have been his way of focusing, since he could read well and experienced no problems using the tutorial.

None of the other navigation problems (using the *Next* and *Back* buttons, continuing at the end of an activity and providing own input) were evident during the eye tracking and observations in this implementation cycle. This indicates that the modifications to rectify navigation problems were successful.

7.4.2.4 Reading skills

As in the first implementation cycle, in general students who could read reasonably well (participants 2, 4 and 7), passed the examination at the end of the semester, while those who did not read well, with the exception of one, failed. The remaining participant who failed could read well, but struggled with mathematics. This corresponds with the results of the statistical analysis regarding the effect of participants' mathematics and English skills, as used in the profile score, on their final mark.

The behaviour and eye movements of participants 2, 4 and 7 as captured during the eye tracking indicated that they can read well and they also experienced no problems in using the tutorial. Participant 1 read quite slowly, although he really made an effort to understand, by repeatedly reading the explanations and trying to reconcile the program code, the variable diagrams and the Console Window. However, he tired after about 45 minutes and started paying less attention, reading less and sometimes clicking the *Next* button to continue without reading the program code or explanations.

Judging by the speed of his eye movements and his behaviour, participant 3 could not read well. He frequently used the mouse to guide his reading and muttered all the time, reading aloud softly. He also returned to text several times and seemed to struggle to understand, frowning and fidgeting. He would prefer an auditory explanation “to understand it more in depth. Reading it doesn't mean we understand what they say especially if you don't have a programming background”. This indicates that though he could decode the text (one of the main components in reading), he could not comprehend what he had decoded (the second main component in reading). He also recommended giving out “sound disks that explain every chapter”, confirming that he struggled to understand what he read.

Participant 5 seemed to read well, judging by the speed of his eye movements and the time taken to read the instructions (13 minutes), although his Mathematics may be weak. It seemed as if he found calculations more difficult, since he spent considerable time to figure it out. His recommendation to incorporate the use of brackets for calculations in the tutorial since “if you make a mistake with BODMAS, you’re basically out”, confirms this. He would prefer not to have auditory explanations.

Participant 6 read quite slowly, often rereading the same line with very long fixations on words or phrases. He also used the mouse to guide his reading, and sometime displayed erratic eye movements. He spent minutes at a time to reconcile the program code, explanations and the contents of the Memory Box, repeatedly rereading and rechecking boxes. He seemed puzzled at times indicating that he did not understand.

In summary, similar to the first implementation cycle, participants who could read well, passed the examination, and those who did not pass either could not read well or struggled with mathematics.

7.4.3 Analysis of the questionnaire completed after eye tracking

The questionnaire that participants answered after their eye tracking and observation session is available in Appendix C.4. Six participants indicated that they had not used the Drawing Variable Diagrams Tutorial before. Four of the participants indicated that they have drawn variable diagrams before. Three of them found it easier to draw variable diagrams after they had used the tutorial. The remaining participant said that it did not make a difference really, but that using the tutorial while working through the section on variable diagrams in the Study Guide, would have made it easier to master the process. Three of the four who had drawn variable diagrams before, said that they drew variable diagrams occasionally to help them understand programs in the Study Guide, one of them only when she got stuck. The other participant said that he had not done so in the past, but intends to do so in future. Of the three participants who indicated that they had never drawn variable diagrams before, one nevertheless claimed to draw variable diagrams to help him understand the programs in the Study Guide although he had not yet received his study material (he was repeating the module though).

All the participants agreed that the questions in the activities helped them to concentrate or understand the variable diagrams. Three participants wanted auditory explanations, three preferred not to have it and one would like to have the option. Participants who could read well preferred the tutorial without audio, although one of them recommended a toggle switch for sound to explain more difficult sections. In contrast, three of the four participants who did not pass, would like to have auditory explanations. These three participants also struggled with reading.

The participants made the following suggestions to improve the tutorial:

- Reducing the explanations about libraries used, namespace and the body of the code in later activities.
- Issuing CDs with explanations for every chapter as well as summaries of certain chapters in the Study Guide, in particular a summary of variables.
- Incorporating the use of brackets in calculations.
- Adding a toggle switch with sound for explanations or help.

One participant found the += operator and the `while` loop in the retrospective comprehension test program confusing, and another indicated that “calculations are a bit tricky. One needs to make use of BODMAS law throughout the calculations”. This indicates a possible problem with the mathematical background of some students.

Five participants gave positive feedback on their experience of using the tutorial and the use of variable diagrams. One participant termed it a “fun and engaging way to learn”, while another reported that “it was amazing to witness the logic behind declaring and storing values in variables and the practical view of it”. Participant 4 also believed that if she had used the tutorial while working through the section on variable diagrams she would have mastered it in a shorter amount of time. One participant found variable diagrams “a lil bit confusing when you draw them”. The last participant declined to give any feedback on his experience.

From the above discussion, the adaptions made to the Drawing Variable Diagrams Tutorial and following its application in the context of this research, as well as aspects concerning its future use, are summarised as follows:

- The updated instructions seemed to serve the purpose, since all participants were able to use the tutorial as intended once they had read the instructions. All participants read the instructions and all were either able to reconcile or make an effort to reconcile the four boxes in activity screens. No participant experienced navigation problems that hampered their use of the tutorial.
- Three participants pointed out an error in activity 9.a.v, namely that the loop stops at 15 instead of 20 as indicated in the program, a mistake introduced during the adaptions for the second implementation cycle.
- The remaining problems in using the tutorial appeared to be students' reading skills and/or mathematical skills. In general the better performing students read well (participants 2, 4 and 7) while those who could not read well, failed (participants 1, 3 and 6). The exception was participant 5, who could read well, but appeared to find Mathematics demanding. Two participants used the desktop calculator to do or check calculations (participants 2 and 6). Although participant 2 passed at the end of the semester, participant 6 failed. While this is not proof that a good ability in Mathematics and English are required to pass the module, it corresponds with the role that the profile score played as a factor in predicting a student's final mark.
- The only change made to the Drawing Variable Diagrams Tutorial for future use, was to correct the error in activity 9.a.v pointed out by three participants. The recommendations for improvements had not been incorporated for the following reasons:
  - The suggestion about reducing the explanations about libraries used, namespace and the body of the code in later activities, was not implemented, since it was deemed to benefit weaker students to repeat it.
  - Explanations on CD would be better implemented as podcasts and can be incorporated in future in the study material for the course.
  - Brackets are not used in calculations when programming in real life, unless it is necessary. Students' lack of adequate mathematical background should be addressed somewhere else.
  - The reasons why sound had not been incorporated as part of the tutorial were explicated on in Chapter 5. In brief, these include a higher cognitive load when information from two channels (visual and auditory) have to be combined; written explanations being more effective and easier to follow than spoken explanations with flexible execution control (when moving backwards and forwards through the tutorial); and a foreign accent adding to the cognitive load (many of the students study in their second or third language). These reasons were still considered valid, especially in the light of the vast difference in reading ability of the students.

In the next section the feedback from students on the COS1511 forum on using the Drawing Variable Diagrams tutorial is discussed.

7.5 Feedback from students in second implementation cycle

During the second implementation cycle in 2013, students were once again invited to provide feedback in both semesters on their experiences while using the Drawing Variable Diagrams Tutorial. Eight students in total responded. Four of them provided feedback on the benefits and shortcomings as well as a general view of the tutorial.

On the positive side, the visualization was considered to make learning and understanding easier. The interactivity and the ability to navigate forward and backward were considered beneficial. The design with the four boxes to display code, explanations, memory and the output was seen as well-implemented and intuitive. The exercises that provide immediate feedback and solutions drew positive comment. The tutorial was considered to be “very effective in communicating the necessary skills to be acquired” while making learning “a bit more fun and interactive”. Three of the students who responded were programmers and considered variable diagrams excellent tools for debugging and for teaching novices “to start learning to read code”.

Four students who had not received the CD with their study material struggled to download it from the Unisa student system. It was recommended that all the activities and the executable file be bundled together in a zipped file for downloading purposes. One student found it frustrating that the tutorial only ran in a Windows environment. Another complained that it went “full screen” and prevented him from working on another application at the same time. He would also have liked better graphics and colour use as well as “auditory stimulation” and links to additional exercises. Two students found it difficult to understand value and reference parameters and one of them advised others to work several times through the relevant activities.

In conclusion, general feedback from respondents commended the tutorial as follows:

- “Overall achieving the end goal of teaching the necessary skills (I would love to see this applied to other subjects – especially maths).”
- “Overall, very practical and brings a sense of being in a classroom with a guided lesson through practical examples and exercises.”
- “I think the package is good educational tool and further development thereof should be encouraged as many future students can benefit from it.”
- “Overall though, I feel that the tutorial itself is an excellent idea and will continue to benefit many aspiring programmers in the future!”

In response to the problems students experienced in downloading the tutorial, a zipped version was provided on the Unisa student system for future use.

7.6 Findings

The quantitative investigation in this implementation cycle aimed to answer research questions 2 and 3, with the qualitative investigation answering question 4. As discussed in sections 7.1 and 7.2, the low response rates in both semesters of 2013 prevented repeating the modelling that was done in the statistical analysis during the first implementation cycle. As a result only descriptive statistics could be calculated for the quantitative investigation in the second implementation cycle.

The descriptive statistics revealed that the second-implementation respondents were an academically stronger student cohort, with better mean final marks than first-implementation respondents. The mean percentages for Mathematics and English for second-implementation respondents in comparison to first-implementation respondents confirm this.

Students' biographical properties as expressed in the profile scores also pointed to an academically stronger student cohort. The majority of both first and second semester students obtained a profile score of between two and four (78% and 72% respectively), in comparison to the first implementation cycle where the majority of respondents had profile scores of between zero and two (56% and 70% respectively for the two semesters). However, the small number of responses prevent any claim of generalisation to the 2013 student cohort.

Due to the small number of responses, it could not be determined whether the improved tutorial assisted students in acquiring programming skills (*research question 2*). Respondents did not rate their learning experience very high (3.54 and 3.22 respectively for the two semesters), thereby indicating that respondents either were undecided as to whether they benefited from using the tutorial, or that it only assisted them to some extent. Respondents were not convinced that the tutorial assisted them in mastering tracing – 55% of first-semester respondents responded positively while only 47% of second-semester respondents concurred. First-semester respondents were more positive about their learning experience, with 68% believing drawing variable diagrams improved their programming skills and 81% that it assisted with understanding the flow of logic in a program. Only 56% of second-semester respondents felt that drawing variable diagrams improved their programming skills, while 61% believed it assisted with understanding the flow of logic in a program. While it seems as if the tutorial helped first-semester respondents to understand simpler constructs, it did not assist with the more complex concepts. Second-semester respondents rated their learning experience for almost all concepts and constructs negatively, but a larger proportion of them also used the tutorial for a shorter time than first-semester respondents. Although respondents indicated that the updated Instructions assisted them in using the tutorial (66% and 52% respectively for the two semesters), it is noticeable that the majority of respondents did not use the tutorial after submitting Assignment 1 (only 20% and 45% continued using the tutorial after submitting Assignment 1). This explains why the tutorial did not assist them with the more complex concepts. Nevertheless, 85% of first-semester respondents indicated they would use variable diagrams in future, while 34% of second-semester respondents felt the same.

In the first implementation cycle the statistical analysis showed that students' biographical properties (prior programming experience, Mathematics and English marks, and first registration or not for COS1511) had by far the biggest impact on their final marks. Although the number of responses was too small to allow for statistical modelling or claiming that any of the findings could be applicable to the 2013 COS1511 population, a correspondence between a higher profile score and a higher final mark was also found in this implementation cycle (*research question 3*). Respondents in the first implementation cycle, who were employed as programmers and therefore classified as being experienced in programming, achieved the highest marks and those who spent less than one hour using the tutorial, achieved the highest marks. In this implementation cycle a relatively large per centage (32% in the first semester and 48% in the second semester) used the tutorial for less than one hour, while 54% in the first semester and 46% in the second semester, used the tutorial for up to 10 hours. This could be because they did not need the tutorial since their programming experience or biographical background enabled them to cope without it, as the higher profile scores seem to indicate.

Respondents expressed slightly less positive user experience scores than in the first implementation cycle of 3.65 for the first semester and 3.26 for the second semester, indicating a user experience of between 'Neutral/Undecided' and 'To some extent'.

The qualitative investigation discussed in sections 7.4 and 7.5, aimed to enhance the answers to research questions 3 and 4, by investigating students' interaction with the tutorial as well as their user experience of it. The direct live observation and eye tracking of participants discussed in section 7.4, revealed three of the four problems identified during the direct live observation and eye tracking observations in the first implementation cycle, have been eliminated, namely –

- learning how to draw variable diagrams from using the tutorial;
- insufficient instructions on how to use the tutorial; and
- problems to navigate intuitively through the tutorial.

All participants were able to use the tutorial as intended once they had read the instructions, and all were either able to reconcile or made an effort to reconcile the four boxes in activity screens. This is an indication that participants were able to learn how to draw variable diagrams from using the tutorial, and that the updated instructions serve the intended purpose. None of the participants experienced navigation problems that hampered their use of the tutorial. However, the fourth problem identified in the previous implementation cycle, namely lack of reading skills hampering understanding and learning from the tutorial, still remained an issue. As before, students who achieved higher marks could read well and those who did not perform well exhibited a poorer reading ability, which may tie in with a lower profile score.

As in the first implementation cycle, a very small number of students provided feedback on the COS1511 discussion forum, as discussed in section 7.5. Nevertheless, the positive feedback indicated that students believed the tutorial to be effective in making both understanding and learning how to draw variable diagrams easier. They also found the tutorial to be well-designed and intuitive. Negative feedback revealed that some students who did not receive the CD with their study material experienced problems downloading the tutorial from the COS1511 course website. This was addressed for future use by bundling all the activities and the executable file together in a zipped file for downloading purposes.

Despite the small sample sizes, responses to question 15 (Did watching the Instructions to learn how to use the Drawing Variable Diagrams tutorial, help you?) in the quantitative investigation confirmed that the updated Instructions assisted students in using the tutorial.

Both the correspondence between a higher profile score and a higher final mark in the quantitative investigation as well as the findings from the qualitative investigation confirmed the answer to research question 3 found in the first implementation cycle, namely that students' educational background as expressed in the biographical profile score, contributed largely to their final marks for COS1511.

As in the first implementation cycle, students in the qualitative investigation who could read well performed better in the examination, and found using the tutorial easier. The respondents in the quantitative investigation in the second implementation cycle had higher means for mathematics and English, with higher means for their final marks. This would tie in with better reading ability and better performance, should it have been possible to generalise.

With regard to research *question 4*, the qualitative investigation confirmed the value of the two lessons learnt in the previous implementation cycle, namely that –

- students should be made aware of the purpose of a visualization; and
- they should receive detailed instructions on how to use it, especially if they are expected to do so on their own, as in an ODL environment.

In the next section the lessons learnt during this research effort are incorporated in the framework of guidelines for using and creating visualizations.

7.7 Enhancing the framework of guidelines for using and creating visualizations

The final step in design-based research involves reflection on the research conducted, in order to produce ‘design principles’ and enhance solutions implementation. At the completion of this study the researcher reflected on the following –

- The framework of guidelines for using and creating visualizations as presented in Table 5.1 in section 5.3.
- Lessons learnt during the development of the tutorial (section 5.4.4.1).
- Lessons learnt during the initial testing of the tutorial (section 5.4.4.2).
- The findings of the two implementation cycles, in particular those of the qualitative investigations.
- The four general guidelines resulting from the development and initial testing process (section 5.4.5), namely:
  - Build in elements to deliberately assist users in consolidating mental models.
  - Reduce extraneous cognitive load as much as possible.
  - Promp users judiciously
  - Test the PAV tool stringently on four different levels: the correctness of content, sequence of execution order, format and didactics.

The intention of the reflection was not to change to framework of guidelines, but to refine it by incorporating the lessons learnt during the research effort. This was done by expanding guidelines 6, 10, 11, 16, 17 and 23; and adding two additional guidelines, namely guidelines 27 and 28.

According to guideline 6, students should be properly guided in how to use the PAV tool. This can be done by including a brief textual introduction and providing resources that help learners interpret the graphical representation that maps the visualization to the underlying algorithm by explaining it with text or narration, or reinforcing the relationship with instructional time during the course. To expand this, the researcher recommends that detailed instructions should be provided, in particular when a PAV tool is used in an ODL environment. It is highly recommended that a way should be found to compel users to work through the instructions for using the PAV tool before engaging with it for the first time. The expansion is based on the findings of the qualitiative investigations.

Guideline 10 recommends applying the modality principle. Modality refers to the sensory mode in which verbal information is presented: written or spoken. In cognitive load theory the modality principle suggests that textual explanations in animations should be presented in spoken format, as this allows more information to be processed visually. To expand this, it should be taken into account that since the modality principle is not always applicable users should be allowed an option for auditory explanations in conjunction with textual explanations. This expansion is based on feedback from participants during the qualitative investigation.

According to guideline 11 using extraneous material (words, sounds, video, and pictures) should be avoided. This guideline is expanded by the recommendation to reduce extraneous cognitive load as much as possible, as discovered during the development and initial testing process, and confirmed by the qualitative investigation's analysis.

Guideline 16 advises applying Tversky et al.'s (2002:257) congruence principle which states that "the structure and content of the external representation should correspond to the desired structure and content of the internal representation". The animation should therefore present the process or procedure in the same way and order that people visualize it. The recommendation to use this as a means of consolidating mental models deliberately expands this guideline. The expansion is based on the four general guidelines resulting from the development and initial testing process.

Guideline 17 proposes using signalling, or cueing to draw the user's attention to critical areas of the visualization, for instance by using different colours, highlighting algorithmic actions, underlining words or using arrows to focus attention on a specific part of the animation. The researcher expands it by counselling that signalling or cueing should also be used judiciously to assist with navigation through the PAV tool, by providing clear indications on how to navigate through the PAV tool, without adding additional cognitive load. This expansion follows from analysis and findings of the qualitative investigation.

Guideline 23 recommends adaping to the knowledge level of the user (the learner). For instance, use a less complicated system for novices and base appropriate feedback on the assumed background knowledge of users, which should be made clear. Expanding this guideline advises investigating users' demographic background and reading ability which should be taken into account before the design and development of the PAV is done. This expansion to the guideline follows from the findings of the qualitative investigation.

Two additional guidelines are added to the framework, namely guidelines 27 and 28. Guideline 27 recommends testing the PAV tool stringently regarding the correctness of content, sequence of execution order, format and its didactical purpose. This is based on the researcher's experiences during the initial testing of the tutorial.

Guideline 28 in turn, advises educating users about the purpose of the PAV tool before they engage with it for the first time, to avoid unrealistic expectations and to ensure that they use it appropriately. This guideline results from the findings of the qualitative investigation.

The final framework of guidelines for using and creating visualizations is presented in Table F.1 in Appendix F. The expansions and additional guidelines are shaded in green in Table F.1.

In the next section the summary and conclusion of the chapter follows.

7.8 Summary and conclusion

This chapter described the quantitative and qualitative investigations for the second implementation cycle of testing and refinement of the tutorial to teach students to draw variable diagrams. The aim was to continue to provide answers to research questions 2, 3 and 4. However, the low response rates to the questionnaires for the quantitative investigation prevented both statistical modelling and claiming that any of the findings in the quantitative investigation could hold for the 2013 COS1511 population since the small numbers of responses were clearly not representative. As a result only descriptive statistics could be calculated as explained in section 7.2. The descriptive statistics for the quantitative investigation was discussed in section 7.3, while the qualitative investigation was addressed in sections 7.4 and 7.5.

In section 7.3, the descriptive statistics for factors that could influence a student's final mark were described, including two new constructs to represent students' manner of tutorial use and their perception of learning from the tutorial. Although the descriptive statistics cannot be claimed to hold for the 2013 COS1511 population, both the means for English and Mathematics as well as the mean final marks for the respondents were approximately 10% better than those of respondents in the first implementation cycle. The average profile scores were also higher. Respondents rated their user experience of the tutorial lower than in the first implementation cycle, but their manner of tutorial use revealed that the majority only used it up to the time they had to submit the first assignment. This may explain why they indicated that the tutorial did not assist them in mastering the more complex concepts and constructs, since they did not use the tutorial to study it. A significant portion of them indicated that they would continue using variable diagrams in future; and felt that drawing variable diagrams assisted them in acquiring programming skills and understanding the flow of logic in programs. This confirms the value of tracing.

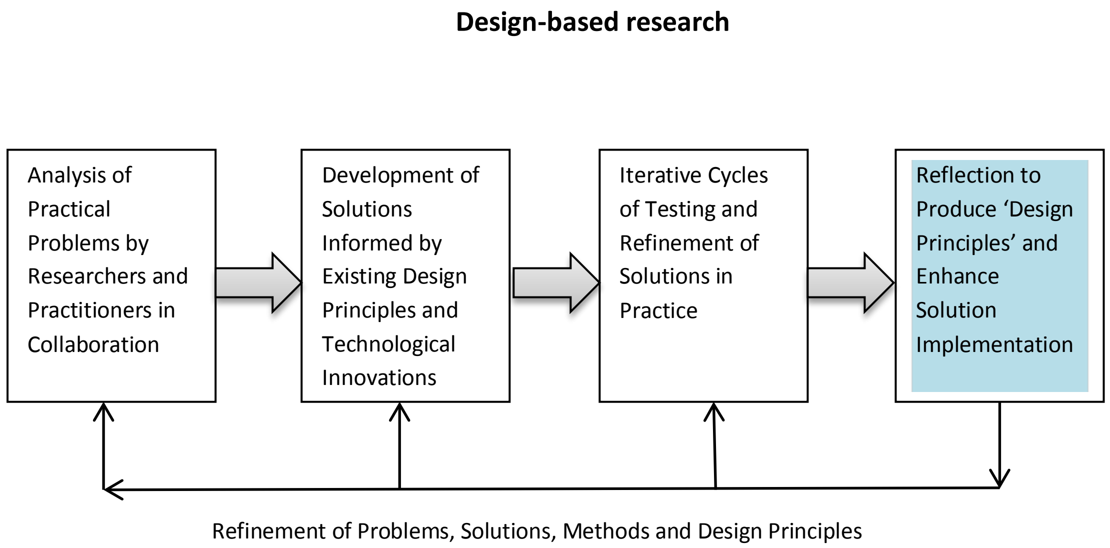
The qualitative investigation with direct observation and eye tracking in the HCI laboratory described in section 7.4 indicated that the updated instructions on using the tutorial succeeded in improving use of the tutorial. It confirmed the findings from the first implementation cycle regarding the role that the lack of reading skills played in a student's use of and possible benefit from the tutorial. It also seemed to confirm the effect that poor reading skills and a lower profile score can have on a student's final mark.

The feedback from the COS1511 discussion forum as presented in section 7.5 indicated that the updated version of the tutorial allowed students to learn how to draw variable diagrams.

In section 7.6 the findings of the second implementation cycle were discussed. In summary, since the quantitative investigation were restricted to calculating descriptive statistics, research *question 2* could not be answered explicitly, but it appeared as if the tutorial did not assist students in acquiring programming skills in Unisa's ODL environment so that it is noticeable in average marks. Similarly the quantitative investigation did not allow for a clear-cut answer to *research question 3*, although it seems to confirm that students' biographical background as expressed in their profile score played an important role in their final mark. Two important lessons learnt in answer to *research question 4* in the first implementation cycle were confirmed, namely that students need be made aware of the purpose of the tutorial and that they should receive detailed instructions on how to use it. These lessons as well as those learnt during the development and initial testing of the framework of guidelines for using and creating visualizations were incorporated in the framework in section 7.7.

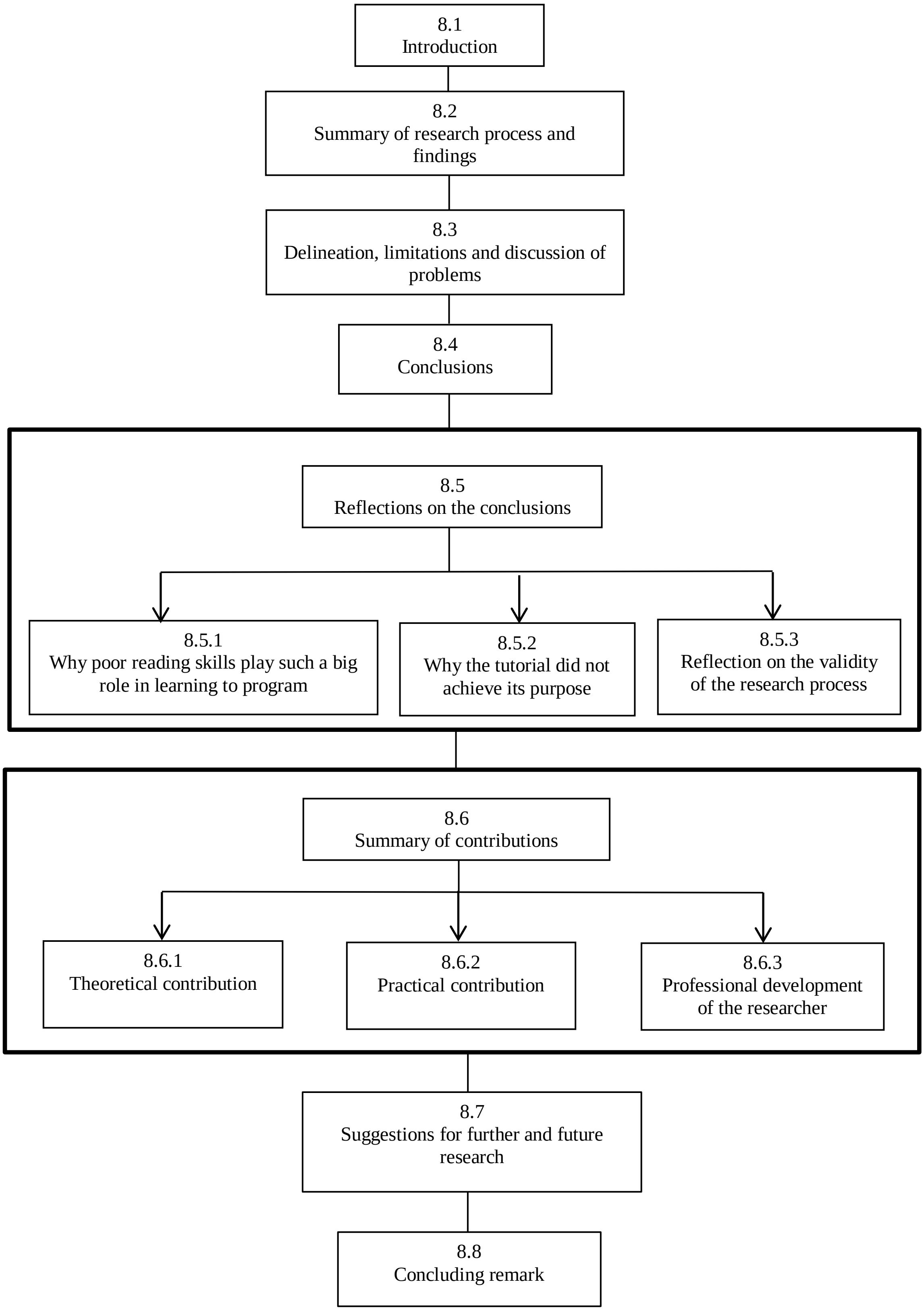
In the next chapter all the findings from this study are drawn together followed by a discussion of the final conclusions and recommendations for future research.

Design-based research phase covered in Chapter 8


Design-based research
Analysis of Practical Problems by Researchers and Practitioners in Collaboration
Development of Solutions Informed by Existing Design Principles and Technological Innovations
Iterative Cycles of Testing and Refinement of Solutions in Practice
Reflection to Produce 'Design Principles' and Enhance Solution Implementation
Refinement of Problems, Solutions, Methods and Design Principles

Phase	**Element**	**Position**
Phase of design-based research (Reeves, 2006)	*Topics/elements that need to be addressed*	*Position in this thesis*
PHASE 1: Analysis of practical problems by researchers and practitioners in collaboration	Statement of problem	Chapter 1, Section 1.3.1 Chapter 4, Section 4.3.2.1
	Consultation with researchers and practitioners	Chapter 4, Section 4.3.2.1 and section 4.3.4.3
	Research questions	Chapter 1, Section 1.3.3 Chapter 4, Section 4.3.2.3
	Literature review	Chapters 2 and 3, Section 5.2
PHASE 2: Development of solutions informed by existing design principles and technological innovations	Theoretical framework	Chapter 5, Section 5.2
	Development of draft principles to guide the design of the intervention	Chapter 5, Section 5.3
	Description of proposed intervention	Chapter 5, Section 5.5
PHASE 3: Iterative cycles of testing and refinement of solutions in practice	Implementation of intervention (First iteration) Participants Data collection Data analysis	Chapter 6
	Implementation of intervention (Second and further iterations) Participants Data collection Data analysis	Chapter 7
PHASE 4: Reflection to produce 'design principles' and enhance solution implementation	Design principles	Chapters 5, 6 and 7
	Designed artefact(s)	Available on course website
	Professional development	Chapter 8

Map of Chapter 8 (Conclusion)


8.1
Introduction
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Summary of research process and findings
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Delineation, limitations and discussion of problems
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Conclusions
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Chapter 8 Conclusion

8.1 Introduction

This research was aimed at improving the tracing skills of introductory programming students at Unisa by means of the COS1511 module Drawing Variable Diagrams Tutorial to teach them to trace. A framework of guidelines for using visualization tools to teach programming was compiled from the literature to guide the design of the tutorial. The investigation also intended to determine whether the tutorial would assist students in the ODL environment at Unisa to the extent that it impacts on the module pass rate.

In section 8.2 the research findings are described based on the research questions following from the thesis for this study. In section 8.3 the delineation, limitations and problems experienced during the study are discussed. The conclusions are presented in section 8.4, with the researcher's reflections on the conclusions in section 8.5, and a summary of the contributions in section 8.6. Suggestions for future and further research follow in section 8.7 and a concluding remark in section 8.8.

8.2 Summary of research process and findings

The thesis for this study was as follows:

A framework of guidelines for using and creating visualization tools to teach programming, synthesized from literature and tested and refined through practical application, can be employed to develop a PV tool to teach introductory programming students in an ODL environment, to trace programs in order to improve students' programming skills.

To test the thesis four research questions were posed. Design-based research, which delivers both a practical and theoretical contribution, was used to investigate the research questions. The design-based research effort consisted of four phases (see Table 4.3). In the first phase (analysis of practical problems by researchers and practitioners in collaboration) the problem statement (sections 1.2 and 4.3.2.1); the research questions (sections 1.3.3 and 4.3.2.3); consultation with researchers and practitioners (section 5.2); and the literature review providing the background to the study (Chapters 2 and 3) were discussed. The three remaining phases were addressed in the investigations to find answers for the research questions.

In the literature review the following topics were covered –

- the ODL learning environment (section 2.2);
- teaching programming in distance education (section 2.3);
- teaching introductory programming courses (section 2.4), including the pedagogy thereof; mental models; threshold concepts and LEM; and the problems novices experience;

- tracing (section 2.5), by defining the concept of tracing; its purpose; difficulties novices experience with tracing; and the advantages of teaching tracing;
- visualization (section 2.6) with an overview of SV; using SV in education; and the success of SV; and
- the BRACElet project (Chapter 3) which served as motivation for this study. (The BRACElet project's findings were used as departing point for this study. In Chapter 3 the background and history of the BRACElet project; its contribution to understanding how novices learn to program; the theoretical foundations; and follow-up research were discussed).

The research questions and the processes followed to answer them are briefly described below with indications of the sections where the findings were discussed in detail:

1. *What guidelines and principles for using and creating visualizations to teach programming, can be derived from literature?*

To answer this question, guidelines for using and creating visualizations were extracted from a literature survey in three areas, namely CER, educational psychology and computer graphics. This process was part of the second phase in the design-research process, that is, development of solutions informed by existing design principles and technological innovations. These guidelines were combined in a framework of 26 guidelines for developing and using visualization tools to teach programming, as presented in Table 5.1 in Chapter 5. Several of the guidelines that appear in more than one of the three areas were synthesised into a single guideline. Guidelines were supplemented with reasons or explanations for their recommendation as well as considerations to be taken into account when using a guideline. References for each guideline, reason or explanation and consideration are provided. Compiling the framework of guidelines was part of the fourth phase, namely reflection to produce 'design principles' and enhance solution implementation.

2. *Will a tutorial to teach tracing to visualize program execution and parameter transfer, based on the framework of guidelines, assist students in acquiring programming skills in an ODL environment so that it is noticeable in average marks?*

This question was answered by developing the Drawing Variable Diagrams Tutorial and implementing the tutorial in practice. The design and development of the tutorial was described in section 5.4 in Chapter 5. This was the final part of the second phase in the design-research process. The third phase in the design-based research process was the testing and refinement of the solutions in iterative cycles in practice. The implementation of the tutorial with two similar iterative cycles of testing and refinement in practice was described in Chapters 6 and 7. During each implementation cycle the tutorial was distributed to the COS1511 students in both semesters. Feedback on their use of the tutorial was gathered by means of questionnaires for quantitative analysis; as well as direct live observation with eye tracking in the HCI laboratory, and requests for feedback on the online forum for COS1511 for qualitative analysis. The questionnaires were analysed in combination with their final marks for the COS1511 module to answer the second and third research questions. The findings from the direct live observation with eye tracking as well as the feedback on the forum was used to refine the tutorial for subsequent implementation cycles and to cast more light onto the findings from the quantitative investigation.

The statistical analysis for the first implementation cycle in 2012 revealed that the findings by the BRACElet project (Lister et al, 2009; Lopez et al., 2008) regarding the correspondence between both students' abilities to explain the purpose of code and to write code; and to trace code and to write code; as well as the correspondence between the combination of these abilities and writing code, also hold for the COS1511 students who wrote the examinations at the end of the two semesters. In theory then, should using the tutorial have assisted them in improving their programming skills, it should have been noticeable in increased pass rates or in the average final mark. However, the modelling done in the statistical analysis for the first implementation cycle in 2012 showed that students, who used the tutorial, achieved lower marks than those who did not use it (sections 6.3.4.2 to 6.3.4.4).

The low response rates in both semesters to the questionnaires administered in the second implementation cycle in 2013 prevented repeating the statistical modelling done in the first implementation cycle. Consequently only descriptive statistics was calculated for the quantitative investigation, and those could not be generalised to the 2013 COS1511 population. Nevertheless, only 55% of the first-semester respondents and 47% of the second-semester respondents in the second-implementation cycle indicated that they believed the tutorial assisted them in mastering tracing (section 7.3.4.5). Second-implementation cycle respondents in both semesters also rated their experience of learning from the tutorial between 'Undecided/Neutral' and 'To some extent' (section 7.3.4.5). Although the second implementation cycle therefore did not provide a conclusive answer to this research question, it leans towards confirming the findings from the first implementation cycle.

In summary, the tutorial did not assist students in acquiring programming skills to the extent that it is noticeable in the pass rate or average final mark.

3. *How do students' biographical properties, their positive user experience, their use of tracing and the extent and manner of tutorial use, affect their ability to acquire programming skills in an ODL environment?*

Feedback provided in both the quantitative and qualitative investigations was used to answer this question, which was also part of the third phase in the design-based research process. Due to the low number of responses to the questionnaires in the second implementation cycle, only the quantitative analysis for the two semesters in the first implementation cycle provided conclusive answers. The qualitative investigations in both implementation cycles provided supporting evidence.

In the first implementation cycle, the modelling done in the statistical analysis of the responses to the questionnaires in combination with respondents' final marks indicated that the students' biographical properties as represented by their profile scores, had the biggest impact on their final marks for COS1511 by far. A student's profile score represented a combination of his/her level of programming experience, marks obtained for Mathematics and English in matric and first-time registration for COS1511 or not (sections 6.3.3.2, and 6.3.4.1 to 6.3.4.4).

A mean positive user experience score based on responses to the questionnaires was calculated for both semesters in the first implementation cycle. This indicated that respondents in general found the tutorial useful, with ratings of 3.75 and 3.68 out of maximum of 5 (section 6.3.3.3). However, a positive user experience had a small negative relationship with the final mark (section 6.3.4.1).

Students, who had drawn variable diagrams before enrolling for COS1511, did slightly better than those who had never done so (sections 6.3.4.1 to 6.3.4.3). Drawing their own variable diagrams while working through the Study Guide had virtually no effect (section 6.3.4.1), and drawing their own variable diagrams to debug their programs did not show up as a significant predictor in the final model (sections 6.3.4.1 and 6.3.4.2).

Time spent on using the tutorial, did not show up as a significant predictor in the final model for either of the two semesters in the first implementation cycle (sections 6.3.4.1 and 6.3.4.2). Investigating the relationship between time spent on using the tutorial and the final mark, revealed that students who used the tutorial for less than one hour achieved better marks than anyone else (section 6.3.4.4).

The qualitative investigation in the first implementation cycle revealed four main areas of concern, namely that participants did not seem to learn from using the tutorial how to draw variable diagrams; the instructions on how to use the tutorial were insufficient; participants could not navigate instinctively through the tutorial; and they lacked reading skills. In particular, participants with poor reading skills did not pass the module (sections 6.4.3 and 6.4.4). Some of the feedback on the COS1511 forum confirmed these issues, while other feedback indicated that the tutorial did assist some students in creating a mental model of program execution (section 6.5).

To address deficiencies in the tutorial itself and the instructions on how to use it, the instructions on using the tutorial were expanded substantially, while the tutorial was adapted to explicitly indicate how to navigate through it (section 6.4.5) with the intention of re-investigating the issues in the second implementation cycle.

The low number of responses to the questionnaires in the second implementation cycle in 2013 hampered the quantitative investigation so that only descriptive statistics could be calculated and no claim can be made that this is representative of the population. Although this cannot be generalised, the mean marks for both English and Mathematics for respondents in both semesters in 2013 were approximately 10% higher than the mean marks for English and Mathematics in the first implementation cycle. This resulted in higher profile scores. Higher profile scores corresponded with higher final marks (section 7.3.4.2); confirming that a student's profile score had an important impact on his/her final mark for COS1511.

The scores calculated for positive user experience were slightly lower than in the first implementation cycle, though still positive (section 7.3.4.6). Although the majority of second-implementation respondents had not drawn variable diagrams before (section 7.3.4.4), most of them displayed a positive attitude towards using variable diagrams indicating that they used it while working through the Study Guide (74% and 59% respectively); believed it improved their programming skills (68% and 56%) and assisted with understanding the flow of logic in programs (81% and 61%). While 85% of first-semester respondents would use variable diagrams in future, only 34% of second-semester respondents would do so (section 7.3.4.4).

The descriptive statistics revealed that most of the respondents only used the tutorial up to the time when they had to submit the first assignment. Consequently, the majority spent between zero and ten hours using the tutorial. The majority watched the updated instructions and felt that it helped them to use the tutorial (section 7.3.4.3), indicating the updated instructions made it easier to use the tutorial. Learning experience scores reflecting students' experience of how much they learnt from the tutorial were also calculated for both semesters, with values of 3.54 and 3.22 out of 5 respectively for the two semesters (section 7.3.4.5).

The qualitative investigation in the second implementation cycle showed that both the adaptions to the instructions on how to use the tutorial and the tutorial itself, served the intended purpose, since, once participants had read the instructions, they were able to use and learn from the tutorial as expected; and experienced no problems in navigating through the tutorial. Lack of reading skills, however, still was problematic. This confirmed the finding in the first implementation cycle that participants who read well, could use the tutorial easily and passed the module, while those who struggled to read, experienced problems in using the tutorial and did not pass the module. Feedback on the COS1511 forum indicated that students felt that the tutorial succeeded in making understanding and learning to draw variable diagrams easier and was well-designed and intuitive to use. Negative feedback related to not receiving the CD with the tutorial or issues with downloading it.

In summary, students' biographical properties in terms of their educational background represented by first-registration for COS1511, their marks for Mathematics and English and their programming experience had a far bigger effect on their final marks than their use of the tutorial, positive user experience, their use of tracing or the extent and manner of tutorial use. Furthermore, their reading ability, another indication of the level of their educational background, contributed to the impact of their biographical properties on their final marks. Nevertheless there were indications that some students found the tutorial to be effective.

4. *What lessons have been learnt through the practical testing and refinement of the visualization tool?*

This question is part of the last phase of design-based research (phase 4), consisting of reflection to produce ‘design principles’ and enhance solution implementation. In the second part of Chapter 5 the development and initial testing of the tutorial based on the framework of guidelines, was described, including lessons learnt during the development (section 5.4.4.1) and initial testing (section 5.4.4.2). These lessons resulted in four general guidelines, namely to deliberately consolidate mental models, reduce extraneous cognitive load, prompt users judiciously and test the PAV tool stringently regarding the correctness of content, sequence of execution order, format and didactics (section 5.4.5). The qualitative investigation in the first implementation cycle revealed two further lessons regarding the implementation of visualization tools (section 6.6) which were confirmed by the qualitative investigation in the second implementation cycle (section 7.6), namely to educate students about the purpose of the PAV tool, and to provide detailed instructions on how to use it to best effect.

By reflecting on the framework and the lessons learnt during the two implementation cycles, the original framework is refined (but not changed) by expanding guidelines 6, 10, 11, 16, 17 and 23; and adding two additional guidelines, namely guidelines 27 and 28, as presented in Table 7.14.

In addition to the reflection that was done while investigating research questions 2 to 4, phase 4 of design-based research requires reflection on the professional development of the researcher. This is done in section 8.6 where the output from this research effort is discussed.

8.3 Delineation, limitations and discussion of problems

The delineation of this study entailed -

- conducting the study on only one first-year programming module, COS1511;
- demonstrating selected samples from the Study Guide in the tutorial to teach students how to draw variable diagrams for programming constructs; and
- limiting the investigation into factors that could have affected their final marks to their biographical properties, their positive user experience, their use of tracing and the extent and manner of their tutorial use.

A limitation of the study was using self-selection sampling for both the quantitative and qualitative investigations, which could have led to biased samples in both cases as only students who were willing to partake responded. In the first implementation cycle this did not pose a problem for the quantitative investigation, as enough responses were received to claim that the findings of the statistical modelling would hold for the 2012 COS1512 population (see section 6.3.1). However, in the second implementation cycle in 2013, the number of responses to the questionnaires was far too small to do any statistical modelling so that only descriptive statistics could be calculated (see section 7.2). As a result, the quantitative findings of the first implementation cycle could not be confirmed by the second implementation cycle and the effect of improvements to the tutorial could not be properly investigated.

Although self-selection sampling was also used for the qualitative investigation, the nature of the investigation itself (direct observation with eye tracking in the HCI laboratory) required at least six participants (Pernice & Nielsen, 2009) (see section 4.3.5.3) for the usability evaluation. In the qualitative investigations in both implementation cycles, the number of participants exceeded this number (see sections 6.4.2 and 7.4.1), which lends credibility to the findings.

Changes to the manner in which the module had to be presented (see section 4.3.4.1), was beyond the researcher's control. This in part, is one of the reasons why the responses to the questionnaires in the second implementation cycle were so poor, since questionnaires were no longer allowed to be distributed in conjunction with assignments (see section 7.1). In 2013, the NDINL was renamed NDIT as a new curriculum was implemented and COS1511 was replaced with another module for the NDIT, which would have altered the composition of the COS1511 cohort. However, students who were registered for NDINL before 2013 as well as those who had to repeat COS1511 were still allowed to register for COS1511. Also in 2013, all students were allocated to e-tutors. Both of these changes could have had an effect on the final marks of students in 2013, but since the statistical modelling could not be repeated, nothing can be said about their possible effect.

The heterogeneous composition of the COS1511 student cohort with COS1511 being offered to a variety of degrees and diplomas with deferent prerequisites (see section 4.3.4.1), makes it difficult to generalise the quantitative findings. This is one of the reasons why the findings are interpreted with caution. On the other hand, the large number of students enrolled for COS1511 per semester, combined with the varied qualifications for which they are enrolled, as well as their diverse backgrounds, adds weight to the significance of the statistical results since it allowed the study to offer some of the same benefits as a multi-institutional, multi-national study. In multi-institutional, multi-national studies in computer science education, the number of students per study typically consists of between 100 and 300 students (Fincher, Lister, Clear, Robins, Tenenberg & Petre, 2005). As can be seen from Table 1.1, this study involved far larger numbers of students.

In the next section the conclusions of this research effort are presented.

8.4 Conclusions

Following the discussion of the research findings and the problems experienced, the subsequent conclusions are made:

1. The framework of 26 guidelines for developing and using visualization tools to teach programming was successful in assisting the researcher to develop the Drawing Variable Diagrams Tutorial.
2. The tutorial did not assist students in acquiring programming skills in an ODL environment to the extent that it was noticeable in average marks.
3. Adaptions to the tutorial for the second implementation cycle were successful in making the tutorial more effective in supporting the students, and some students believed they benefited from using it.
4. The biographical properties of students who wrote the COS1511 examinations as characterised by a combination of their level of programming experience, marks obtained for Mathematics and English in matric and first-time registration for COS1511 or not, had an overwhelming effect on their final marks, far more than the manner and extent of their use of the tutorial had.
5. Students' reading skills played a major role in their success or not in COS1511.

In the light of the above, the thesis for this study can only be partially accepted, as it is possible to employ a framework of guidelines for using and creating visualization tools to teach programming, synthesized from literature and tested and refined through practical application to develop a PV tool to teach introductory programming students in an ODL environment to trace programs. It could however not be shown that using the tutorial improved their programming skills to a noticeable extent. The main reason for this was the extent to which the effect of students' biographical properties on their final mark overshadowed the result of their use of the tutorial.

In the next section the researcher reflects on questions prompted by these conclusions.

8.5 Reflection on the conclusions

The conclusions raised the following two questions with the researcher:

1. Why do poor reading skills play such a big role in learning to program?
2. Why did the tutorial not achieve its purpose?

Below, in sections 8.5.1 and 8.5.2, the researcher attempts to find answers to these two questions based on the literature review done for this study. In addition, the researcher reflects on the validity of the research process followed in section 8.5.3.

8.5.1 Why poor reading skills play such a big role in learning to program

According to Gous and Roberts (2014:2623) “The area where reading is computed and represented in the brain originally was used to see objects and navigate terrain. For this reason reading is still related to traversing a terrain, almost like visiting objects in context”. Program code also represents an abstract space that has to be navigated with the same cognitive strategies as used in natural environments, since program comprehension is described as “the process of generating a cognitive map from the program source-code to a set of application domain concepts” (Cox, Fisher & O'Brien, 2005:93). Jones and Burnett (2007) found a strong correlation between students’ spatial ability, that is their ability to navigate, and their results in programming modules, with much lower correlations between their spatial ability and non-programming modules. Students with a low spatial ability also use less effective navigational strategies when attempting to comprehend code (Jones & Burnett, 2007) (See section 5.2.2). This relationship between the area in the brain where reading is processed and navigational ability, explains why students with lower spatial ability struggle more with programming subjects and confirms Chmura’s (1998) finding that students with poor reading comprehension skills struggle to learn to program.

Reading ability is a strong predictor of academic performance (Bertram, 2006; Pretorius, 2002), even in a subject such as Mathematics, which is typically associated with logico-deductive skills (Pretorius, 2002). BRACElet argues that the development of programming skills follows a similar process as the development of mathematical skills (Lister & Edwards, 2010; Philpott, Clear & Whalley, 2009) (See section 3.5.1). Mathematicians consider ‘word problems’ one of the most difficult things to teach, but programming is mostly comprised of solving word problems. The issue seems to be the ability to convert the words on paper to something meaningful to the student (Winslow, 1996), which corresponds with the comprehension and interferencing (that is, the ability to fill in gaps between text elements and link information across textual units (Rickheit, Schnotz & Strohner, 1985)) (see section 6.4.3.4)) parts of reading. The ability to program requires the same type of logico-deductive skills as Mathematics, and if students struggle to read, it will be all the more difficult to convert the words on paper or the program code to something meaningful, that is, to abstract.

As the results of the BRACElet project (see section 3.4) indicate, novices acquire programming skills in the following hierarchical order: firstly by learning to read or trace code; then to explain code; and once reasonably capable of both reading and explaining, to systematically write code. To comprehend program code, interferencing needs to be used to an even greater extent than when reading conventional text. Students who struggle to read, will then also find it difficult to read or trace code, as well as to explain it, because they need to use interferencing to understand the code before they can explain it. Interferencing in reading program code also poses its own difficulties for novices, such as incorrect mapping from natural language to a programming language (Spohrer & Soloway, 1989); and confusing the semantics of programming-language constructs with the related natural-language words and/or mathematical concepts such as assignment (Jimoyiannis, 2013; Khalife, 2006; Simon, 2011; Sorva, 2008; Spohrer & Soloway, 1989) (see sections 2.4.3.1 and 2.4.3.2). This may explain why poor readers find it difficult to learn to program, especially if they experience problems with inferencing.

According to cognitive load theory, learning requires information processing in both working memory and long-term memory. Working memory has a limited processing capacity inhibited by intrinsic cognitive load (the difficulty of the subject matter); extraneous cognitive load (the way information is presented) and germane cognitive load (when information is presented in such a way that it facilitates the construction of cognitive schemas) (Sweller, van Merriënboer & Paas, 1998; Wouters, Paas & Merriënboer, 2008) (see section 5.2.2). The limited processing capacity of working memory corresponds with the limited capacity assumption in the cognitive theory of multimedia learning which assumes that the channels for processing visual and auditory representations (eyes and ears) can only process a limited amount of material per occasion (Sorva, Karavirta & Malmi, 2013) (see section 5.2.2). The tight integration of concepts in a programming language indicates a high intrinsic cognitive load (Robins, 2010) (see section 5.2.2). Reading at the frustration level (where the reader reads with less than 90% decoding accuracy and 60% level of comprehension) or the instructional level (95% decoding accuracy and 75% level of comprehension) (McCormick, 1995) would impose a high cognitive load on working memory (Sweller et al., 1998), making it very difficult to master the subject matter. As a result students who struggle to read will find it difficult to learn to program.

In summary, three reasons why poor reading skills may impact more on learning to program than on learning in other subjects, have been identified, namely –

- the relationship between the area in the brain where both reading is processed and navigational ability is seated, and comprehending program code;
- the higher level of interferencing required to read and understand program code; and
- the high intrinsic cognitive load associated with programming languages which taxes the processing capacity of working memory, which will make it more difficult for poor readers to learn to program.

8.5.2 Why the tutorial did not achieve its purpose

Data from the National Benchmark Test in Academic Literacy show that most of the South-African matriculates are not prepared for tertiary education (Cliff, 2015) (see section 6.3). Many of Unisa's students are in the same boat. Unisa research shows that the average first-year student, from a background where reading was neglected, could have the reading ability of twelve-year olds, not eighteen-year olds (Kilfoil, 2008) (see section 6.3). Children 'learn to read' through decoding, while comprehension enables them to 'read to learn' (Matjila & Pretorius, 2004). By Grades 9 to 12 reading comprehension for complex topics becomes better than listening for successful readers, while listening comprehension is better than reading comprehension for poor readers. During the post-school phase, for highly skilled readers, reading is more efficient than listening as a learning tool (Matjila & Pretorius, 2004; Pretorius & Ribbens, 2005). A typical twelve-year old would be in Grade 7, so that an average first-year Unisa student from a reading-neglected background would not have the skill to learn complex topics by reading. Five out of nine of the participants observed in the HCI laboratory in the first implementation cycle and three out of seven of the participants observed in the HCI laboratory in the second implementation cycle indicated that they would prefer to have auditory explanations added to the tutorial. In both cycles there was also another participant who would have liked the option to have it. This, as well as the fact that some of them displayed erratic eye movements while reading the text in the tutorial, may be an indication of poor reading skills, and would explain why they could not properly utilise the tutorial.

The literature review revealed that there is general consensus that visualizations are only educationally effective if they actively engage learners in activities (Foutsitzis & Demetriadis, 2008; Hundhausen & Douglas, 2002; Hundhausen, Douglas & Stasko, 2002; Naps, Röβling et al., 2003; Pears, Seidman, et al., 2007). Despite integrating the tutorial as part of the study material to ensure students engage with it, as recommended (Ben-Bassat Levy & Ben-Ari, 2007; Lahtinen, 2006; Lahtinen, Jarvinen & Melakoski-Vistbacka, 2007; Röβling, 2010), this did not happen to the degree that was expected, as the findings from the quantitative investigations showed. The average amount of time spent using the tutorial and the fact that most of the students did not continue using the tutorial after they had submitted Assignment 1, certainly did not reflect a “high commitment to visualization” (Isohanni & Knobelsdorf, 2011:38) (see section 5.4.1), which would have been an indication of active engagement and should have allowed students to benefit more from the tutorial.

Academically strong students probably did not need the tutorial (Lahtinen, 2006), as the negative correspondence between the time they spent using the tutorial and their final marks indicated. Average students may have benefited more than weak or strong students (Ben-Bassat Levy, Ben-Ari & Uronen, 2003) (see section 5.4.2), but the bimodal results distribution (see Table 1.1) may have hidden this effect. Some students certainly misunderstood the purpose of the tutorial, as their feedback on the COS1511 forum showed, and maybe they misunderstood the activities too.

Prior experience of using a PV lowered the cognitive load and allowed students to learn more effectively from it (Laakso, Rajala, Kaila & Salakoski, 2008) (see section 5.4.3). Since students did not have the benefit of prior experience of using a PV, the cognitive load might have been too much for some of them, especially if they had poor reading skills. The ‘distance’ in ODL in terms of time, economic, social, educational, epistemological and communication distances between the institution and its students, as well as between students themselves (Heydenrich & Prinsloo, 2010), exacerbated by inadequate reading skills (Gous & Roberts, 2014) (see section 2.2) could well have contributed to this.

According to Lister's (2011) neo-Piagetian theory novices in the first stage of cognitive development, the sensorimotor stage, cannot abstract to reason about a specific problem and can only trace with great difficulty. At this stage they also do not understand that an executing program is a 'deterministic machine' (Corney, Teague, Ahadi & Lister, 2012:2), which is what teaching them to trace is attempting to accomplish. At the preoperational stage, the second stage, while novices have acquired some appropriate abstractions, their abstractions are still fragmented so that they cannot apply a concept spontaneously or use it inappropriately (Lister, 2011; Teague, Corney, Fidge et al., 2012). Although they can trace, they typically cannot abstract from the code to deduce the purpose of the computation (Gluga, Kay, Lister & Teague, 2012; Lister, 2011). In the third stage, the concrete operational stage, novices tend to deal with abstraction by using specific examples to reduce the level of abstraction (Gluga et al., 2012), can relate code to diagrams and comprehend how lines of code comprise a computation (Corney et al., 2012). They may be able to derive the function of a small program fragment just by reading it and using deductive reasoning to determine its purpose (Gluga et al., 2012) without a concrete written trace (Teague et al., 2013). The last stage, the formal operational stage, is the most advanced and the most abstract stage, the level at which expert programmers operate (Lister, 2011; Teague et al., 2013). This is the stage that is expected of computing students at the end of their first year (McCracken, Almstrum, Diaz, Guzdial, Hagan, Kolikant, Laxer, Thomas, Utting & Wilusz, 2001) (See section 3.5.2). COS1511 is a semester module, and it would be unrealistic to expect COS1511 students to have reached this stage after six months of distance education. Rather, it is more realistic to expect successful COS1511 students to have reached the concrete operational stage at the end of their first semester of introductory programming education. However, if their reading ability does not allow them to inference, they will be unable to abstract, and will still be at the sensorimotor stage of cognitive development where they find it very difficult to trace; or at the preoperational stage where even though they can trace, they cannot abstract from the code to determine its meaning. At these stages they will not be able to benefit from the tutorial.

Lastly, the design of the system itself might have been a factor in the level of its success. The qualitative investigation during the first impemetation cycle pointed out that the instructions for using it was insufficient and that students could not navigate intuitively through the tutorial. This indicated that the instructions on how to use the tutorial and how to navigate through the tutorial should be adapted. This was done for the second implementation cycle, but the low response rate prevented repeating the statistical modelling that was done in the first implementation cycle. As a result the quantitative investigation could not indicate whether or not the adaptions to the tutorial had the desired effect (improving students' programming skills). The qualitative investigation in the second implementation cycle indicated that the the changes to the tutorial improved the user experience. This eliminated all the problems identified during the qualitative investigation in the first implementation cycle, except the restrictions imposed by the students' poor reading ability.

In summary, possible reasons why the tutorial did not deliver the expected results, could be –

- poor reading skills that prevented students from utilising the tutorial as expected;
- lack of active engagement;
- a cognitive load that was too high for some of the students to cope with in combination with the 'distance' in ODL education;
- deficiencies in the design of the tutorial itself; and
- students' inability to abstract due to poor reading skills.

8.5.3 Reflection on the validity of the research process

Ensuring validity in design-based research requires treatment validity; systemic validity and consequential validity (Hoadley, 2004) as discussed in section 4.3.2.1.

Treatment validity demands that the intervention represents the theory it tests, and in design-based research the consequences of the intervention supports the validity of its claim (Barab & Squire, 2004). This requires comprehensive documentation of the research process to explain why outcomes occurred. The process of developing the framework of guidelines for developing and using visualization tools to teach programming; the development and implementation of the Drawing Variable Diagrams Tutorial and the iterative cycles of implementation and investigation were described meticulously in the preceding chapters of this study. This supports the treatment validity of the findings. The two publications that resulted to date from this research effort (Schoeman et al. 2012, 2013) also supports treatment validity as does the statistical analysis that confirms the findings of the BRACElet project (Lister et al, 2009; Lopez et al., 2008) (see sections 6.2.2 to 6.2.4).

Systemic validity requires that the research and resulting implications answer the research questions. Using triangulation with both qualitative and quantitative investigations; iterative cycles of implementation and analysis; and using established methodological practices in the research ensured the reliability of the findings.

Consequential validity refers to how the interpreted results can be applied practically for future prediction and implementation. The framework of guidelines for developing and using visualization tools to teach programming provides a tool that can be used by other educators to implement and evaluate SVs. Disclosing the reason(s) for the poor pass rates in Unisa's ODL environment makes a valuable contribution that can be used to implement measures to improve teaching practices at the institution.

This research effort thereby satisfies treatment validity, systemic validity and consequential validity.

In the next section the contributions made by this study is discussed.

8.6 Summary of contributions

The last phase of design-based research (phase 4) consists of reflection to produce 'design principles' and enhance solution implementation. This includes the output from the research, namely design principles, the designed artefact and reflection on the professional development of the researcher. The theoretical contribution constitutes the design principles while the tutorial that was developed represents the practical contribution. In the following sections the theoretical and practical contributions as well as the professional development of the researcher are discussed.

8.6.1 Theoretical contribution

The framework of guidelines for developing and using visualization tools to teach programming as presented in Table 5.1 and enhanced in Table 7.14 represents the theoretical contribution of the study.

No comprehensive framework of this nature has been found by the researcher, although several sets of guidelines for creating visualizations have been presented in the three areas reviewed, as described in section 5.2. Similar guidelines that occurred in more than one of the three areas reviewed were synthesised into one guideline. The different areas covered in the literature survey allowed the researcher to enhance the guidelines with reasons or explanations for their recommendation, as well as with considerations that should be taken into account when implementing them, as some considerations may exclude certain guidelines under specific circumstances. The lessons learnt through the practical testing and refinement of the Drawing Variable Diagrams Tutorial, allowed the researcher to add further value to the framework of guidelines by expanding six of the original guidelines in the framework and incorporating two more guidelines. Both the framework and the lessons learnt can be used by other researchers and educators to either develop new PAVs or evaluate and adapt existing PAVs, although it cannot guarantee the success of the resulting PAVs. Particular emphasis is placed on the importance of considering the demographical background and reading abilities of the intended users. In addition, it should be taken into account that the levels of engagement of the users determine to a large degree whether a PAV succeeds in achieving its purpose or not.

This research effort provides two theoretical contributions to improving computer programming education in the form of –

- the framework of guidelines for developing and using visualization tools to teach programming; and
- some theoretical understanding as to how novices learn to program in the reflection on possible reasons why

- poor reading skills may have such a strong effect on learning to program; and
- the tutorial did not achieve its purpose.

This is in line with the contribution design-based research can make in developing contextualized theories of learning and teaching (Design-based Research Collective, 2003).

8.6.2 Practical contribution

The practical contributions made by this study consist of the development of the Drawing Variable Diagrams Tutorial, tested and refined through two implementation cycles, and the results of the investigations during the two implementation cycles.

Developing the tutorial demonstrated that the framework of guidelines can be utilised for its intended purpose.

Although introducing the tutorial into the study material for COS1511 did not improve the pass rate or class average to a noticeable extent, there was evidence that some students believed they benefited from it, and that it could benefit other students too. The most important contribution however, was revealing the role that students' biographical background, and their reading skills in particular, played in their success or not in studying introductory programming in Unisa's ODL environment. This provided some explanation for a long-standing problem with low pass rates in introductory programming modules at Unisa. It also clarified the real-world demands made on the tutorial, one of the advantages of design-based research (Design-based Research Collective, 2003).

In addition, the results of the quantitative investigation confirmed that the hierarchical development of reading, explaining and writing code that BRACElet found, also holds in an ODL environment.

8.6.3 Professional development of the researcher

This research effort took the researcher on a journey of learning and discovery/understanding – of the vast amount of literature on how novices learn to program and SV; research methods and paradigms; statistical analysis and the challenges of doing empirical research. These challenges included communicating with the implementers of the tutorial, questionnaire design, recruiting participants, obtaining feedback from students, and working with two different statisticians due to unforeseen circumstances.

The researcher learnt that as much as possible of what has to be done, should be put on paper, in such a clear manner that there can be no leeway for misunderstanding. In future research efforts, the questionnaire will be designed in conjunction with the statistician, and much more time spent on the initial planning to decide what and how it will be analysed. Some commitment from the statistician to complete the project will also be insisted on. Recruiting participants remain a very difficult aspect to handle in the ODeL environment, which certainly requires further investigation.

On the level of personal development, the researcher discovered that she has a great deal of perseverance and can work very hard. The researcher also noticed how much her writing skills and capacity to edit her own work developed, which is very gratifying. In this process she gained confidence in her ability to do research.

In addition, the study provided the researcher with more insight in the problems first-time students in the ODL environment at Unisa and in particular, novice programmers face. It made her aware of various possibilities to address these problems, and increased her empathy with novice programming students and her desire to assist them.

8.7 Suggestions for further and future research

Both the theoretical and practical contributions of this research effort offer possibilities for further research directly related to this thesis and future research in the wider context of this study. Future research directly related to this study includes further research on:

- The framework of guidelines for developing and using visualization tools to teach programming can be refined by incorporating more guidelines from educational psychology and computer graphics, as well as the results of the on-going investigations in SVs. This can provide a quick start for new developers or adaptors of PAVs to use as a checklist.
- Adapting the framework for mobile devices can be explored, since mobile learning and e-learning have become important facets of ODeL.
- The researcher is still convinced of the value of teaching novices to trace. Other ways of visualizing tracing can be investigated, for example using podcasts, which may appeal more to students. A podcast demonstrating how to draw variable diagrams for each new concept can be used with students rating how much they learned from it.
- The tutorial itself can be enhanced by including more activities to engage students to see how that affects the user experience and learning experience of students.

Aspects in the wider context that warrant further research are:

- Since most of the students only used the tutorial to a limited extent; and sending e-mails and sms's failed to activate them into responding to the online questionnaires, future research into how to ensure students effectively engage with their study material in Unisa's online environment, should be considered. The effectiveness of current practices such as e-tutors should also be investigated together with possible modifications to make the system more efficient. This could take the form of a survey under students, maybe by phoning them on their cell phones.

- In the light of the important role reading plays in learning to program, an issue that warrants research is how to identify programming students with poor reading skills and how to assist them by improving their reading skills specifically with the aim of learning to program. An educational psychologist should be able to assist with a program to improve reading skills.
- Investigating ways to improve learners' spatial skills in an effort to improve their reading skills and the effect of improve learners' spatial skills on their programming skills, offer another worthwhile research topic. This could be cross-disciplinary research where an occupation therapist prescribes exercises to improve spatial skills, and an educational psychologist assist with improving reading skills. An experiment could be done where both learners' spatial skills and reading skills are tested before and afterwards, while some do the exercises to improve spatial skills and others the program to improve reading skills, for a period. A control group that does not follow either the exercises to improve spatial skills or the program to improve reading skills, should be used included in the research to determine whether either improving spatial skills or reading skills developed their programming skills.

8.8 Concluding remark

Although introducing the tutorial into the study material for COS1511, did not have the desired effect, the research provided valuable insight into the reason(s) for the low pass rate for the introductory programming module in Unisa's ODL environment. The framework of guidelines for developing and using visualization tools to teach programming also contributed a synthesised reference for other educators who wish to incorporate visualization tools in their teaching of introductory programming. In turn, the reflection on the effect of poor reading skills in learning to program adds to the body of knowledge about how novices learn to program.

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Nyalungu, I.V. (vnyalung@unisa.ac.za) (20 March 2015) RE: Pass rate for COS1511 [DIA Task Ref No: MAR15Q34] Distinctions please [DIA Task Ref No: MAR15Q50], E-mail to Schoeman, M. A. (schoema@unisa.ac.za).

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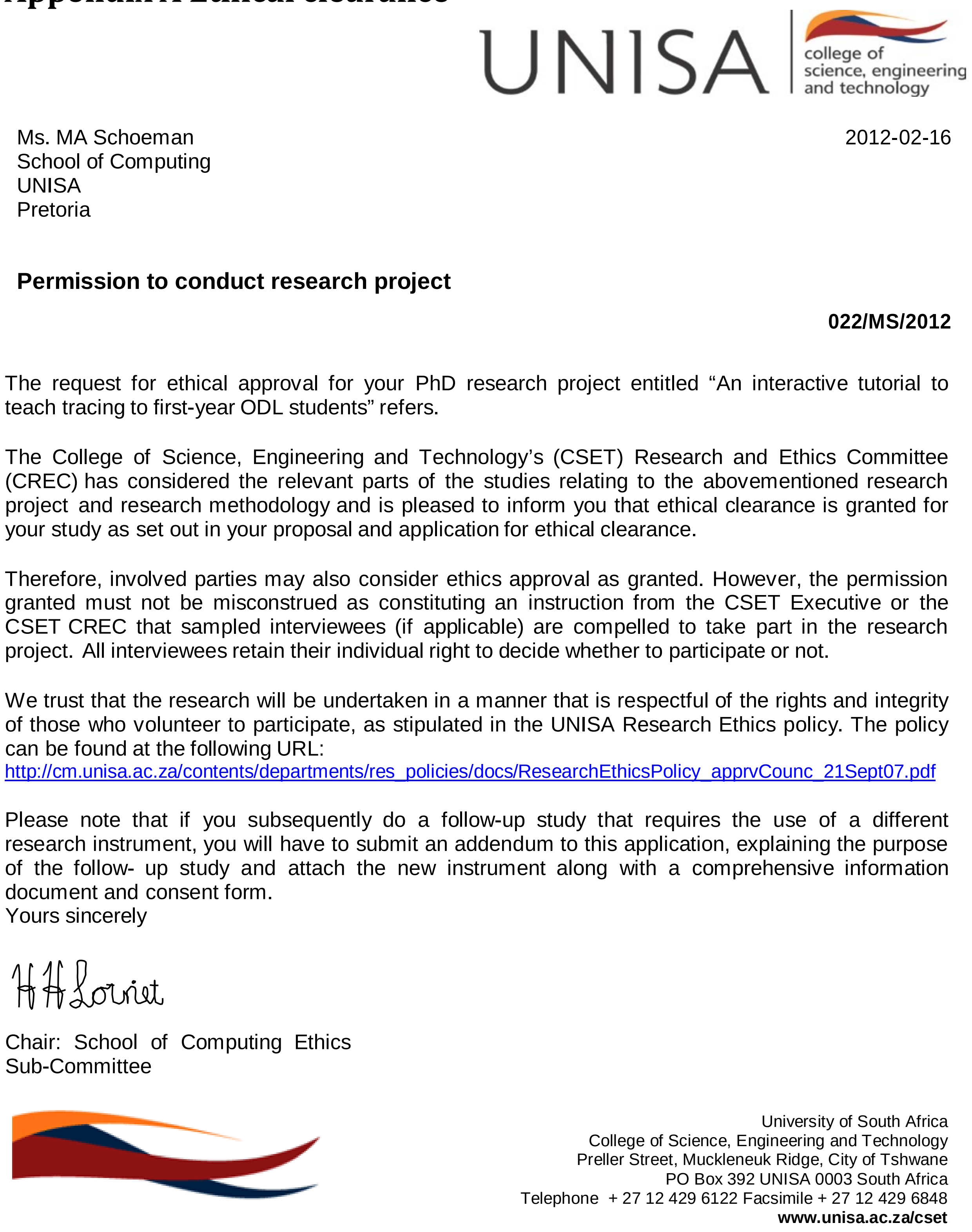
Appendix A Ethical clearance



UNISA | college of science, engineering and technology

Ms. MA Schoeman
School of Computing
UNISA
Pretoria

2012-02-16

Permission to conduct research project

022/MS/2012

The request for ethical approval for your PhD research project entitled “An interactive tutorial to teach tracing to first-year ODL students” refers.

The College of Science, Engineering and Technology’s (CSET) Research and Ethics Committee (CREC) has considered the relevant parts of the studies relating to the abovementioned research project and research methodology and is pleased to inform you that ethical clearance is granted for your study as set out in your proposal and application for ethical clearance.

Therefore, involved parties may also consider ethics approval as granted. However, the permission granted must not be misconstrued as constituting an instruction from the CSET Executive or the CSET CREC that sampled interviewees (if applicable) are compelled to take part in the research project. All interviewees retain their individual right to decide whether to participate or not.

We trust that the research will be undertaken in a manner that is respectful of the rights and integrity of those who volunteer to participate, as stipulated in the UNISA Research Ethics policy. The policy can be found at the following URL:
http://cm.unisa.ac.za/contents/departments/res_policies/docs/ResearchEthicsPolicy_apprvCounc_21Sept07.pdf

Please note that if you subsequently do a follow-up study that requires the use of a different research instrument, you will have to submit an addendum to this application, explaining the purpose of the follow- up study and attach the new instrument along with a comprehensive information document and consent form.
Yours sincerely

H H Lotriet

Chair: School of Computing Ethics
Sub-Committee

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Appendix B Questionnaires used during implementation and testing of Drawing Variable Diagram Tutorial

B.1 Questionnaires used in first implementation cycle

B.1.1 First semester 2012

Mrs MA Schoeman (schoema@unisa.ac.za; tel 012 429 6857) and prof JH Gelderblom (geldejh@unisa.ac.za; tel 012 429 6631) are conducting research on the usability and effectiveness of the tutorial to teach tracing for this module, COS1511. We will appreciate your co-operation in completing this optional part of Assignment 1 (Questions 1 to 21).
The research is conducted under the following conditions:

- Participants are not personally being tested, and their participation will not impact in any way on their assessment in COS1511 assignments or the exam.
- There will be no monetary payment to the participants.
- Participants are free to withdraw from the research or not partake at all, and there will be no disadvantage if they do so.
- In reporting results of this study, no names will be disclosed. Research findings will be communicated at presentations or be published in academic publications, but anonymity and confidentiality will be preserved.
- By completing the questions that follow below on the same mark reading sheet as the rest of Assignment 1, you declare that you are aware of the above information and willingly partake in this research.

Choose only 1 option in each of the following questions:
Question 1 Gender?

1. Male
2. Female

Question 2 What is your age?

1. 19 - 22
2. 23 - 27
3. 28 - 32
4. 32 – 40
5. 41 +

Question 3 Which ONE of the following describes your situation best?

1. I am a full-time student who does not work at all.
2. I am a full-time student who works part-time for extra pocket money (not to pay for my studies).
3. I am a full-time student who works part-time to pay for my studies.
4. I work full-time and study after hours, and the work that I do is not related to my degree at all.
5. I work full-time and study after hours, and the work that I do is related to my degree

Question 4 My highest qualification is

1. Matric
2. National certificate
3. Diploma
4. Degree
5. Post-graduate degree

Question 5 My first language is

1. English
2. Afrikaans
3. Other

Question 6 In my matric results*

1. I passed Mathematics (higher grade) or equivalent with a C-symbol or higher.
2. I passed Mathematics (higher grade) or equivalent with a D-symbol or lower.
3. I passed Mathematics (standard grade) or equivalent with a C-symbol or higher.
4. I passed Mathematics (standard grade) or equivalent with a D-symbol or lower.
5. I did not take Mathematics for matric.

*Students who do not have a South African matric should choose the options they think are most relevant to them.

Question 7 In my matric results*

1. I passed English (higher grade) or equivalent with a C-symbol or higher.
2. I passed English (higher grade) or equivalent with a D-symbol or lower.
3. I passed English (standard grade) or equivalent with a C-symbol or higher.
4. I passed English (standard grade) or equivalent with a D-symbol or lower.
5. I did not take English for matric.

*Students who do not have a South African matric should choose the options they think are most relevant to them.

Question 8 Did you have Computer Applications Technology, Information Technology or Computer Studies at school?

1. Yes
2. No

Question 9 What level of ***computer literacy*** do you have? If you have done more than one, choose the option reflecting the most recent one you have done.

1. Self-taught
2. Did Computer Applications Technology, Information Technology or Computer Studies at school
3. Passed or enrolled for ICDL or EUP at Unisa
4. Done any other computer literacy course
5. Use a computer daily at work

Question 10 What experience do you have in ***programming***?

6. Computer Studies or Information Technology at school
7. Repeating COS1511
8. Currently enrolled for another programming module at Unisa
9. Did a programming course other than COS1511
10. Employed as a programmer

Question 11 Which ONE of the following is applicable to you?

1. This is my first registration for COS1511.
2. I have been registered for COS1511 or COS111U before but have never written the examination.
3. I have written the examination for COS1511 or COS111U once before.
4. I have written the examination for COS1511 or COS111U twice before.
5. I have written the examination for COS1511 or COS111U three or more times before.

Question 12 Have you drawn variable diagrams before enrolling for COS1511?

1. Yes
2. No

Question 13 Do you use the tutorial for this module while working through the study guide?

1. Yes
2. No

Question 14 Do you draw your own variable diagrams to help you to understand programs in the study guide?

1. Yes
2. No

Question 15 Do you draw your own variable diagrams to debug your programs?

1. Yes
2. No

Question 16 Up to now, how much time in total, have you spent using the tutorial?

1. Less than 1 hour
2. 1 to 3 hours
3. 4 to 6 hours
4. 7 to 8 hours
5. More than 8 hours

Question 17 To what degree did the tutorial assist you to master tracing?

1. Not at all
2. Neutral
3. A little bit
4. Fairly useful
5. Very useful

Question 18 Did you find it interesting to use the tutorial?

1. Not at all
2. Neutral
3. A little bit
4. Fairly interesting
5. Very interesting

Question 19 Did you find it motivating to use the tutorial?

1. Not at all
2. Neutral
3. A little bit
4. Fairly motivating
5. Very motivating

Question 20 To what degree did you enjoy using the tutorial?

1. Not at all
2. Not really
3. Neutral
4. Moderately
5. Very much

Question 21 Did you find it irritating to use the tutorial?

1. Not at all
2. Neutral

3. A little bit
4. Fairly irritating
5. Very irritating

B.1.2 Second semester 2012

Mrs MA Schoeman (schoema@unisa.ac.za; tel 012 429 6857) and prof JH Gelderblom (geldejh@unisa.ac.za; tel 012 429 6631) are conducting research on the usability and effectiveness of the tutorial to teach tracing for this module, COS1511. We will appreciate your co-operation in completing this optional part of Assignment 1 (Questions 1 to 21).

The research is conducted under the following conditions:

- Participants are not personally being tested, and their participation will not impact in any way on their assessment in COS1511 assignments or the exam.
- There will be no monetary payment to the participants.
- Participants are free to withdraw from the research or not partake at all, and there will be no disadvantage if they do so.
- In reporting results of this study, no names will be disclosed. Research findings will be communicated at presentations or be published in academic publications, but anonymity and confidentiality will be preserved.
- By completing the questions that follow below on the same mark reading sheet as the rest of Assignment 1, you declare that you are aware of the above information and willingly partake in this research.

Choose only 1 option in each of the following questions:
Question 1 Gender?

1. Male
2. Female

Question 2 What is your age?

1. 19 - 22
2. 23 - 27
3. 28 - 32
4. 32 – 40
5. 41 +

Question 3 Are you studying full-time or part-time?

1. Full-time
2. Part-time

Question 4 What is your occupation?

1. Unemployed
2. Full-time student
3. IT-related
4. Other

Question 5 What is your highest qualification?

1. Matric
2. National certificate
3. Diploma

4. Degree
5. Post-graduate degree

Question 6 What is your first language?

1. English
2. Afrikaans
3. Other

Question 7 Did you have Computer Applications Technology, Information Technology or Computer Studies at school?

1. Yes
2. No

Question 8 Have you been registered for COS1511 before?

1. Yes
2. No

Question 9 What level of ***computer literacy*** do you have? If you have done more than one, choose the option reflecting the most recent one you have done.

1. Self-taught
2. Did Computer Applications Technology, Information Technology or Computer Studies at school
3. Passed or enrolled for ICDL or EUP at Unisa
4. Done any other computer literacy course
5. Use a computer daily at work

Question 10 What experience do you have in ***programming***?

1. Computer Studies or Information Technology at school
2. Repeating COS1511
3. Currently enrolled for another programming module at Unisa
4. Did a programming course other than COS1511
5. Employed as a programmer

Question 11 Which ONE of the following is applicable to you?

1. This is my first registration for COS1511.
2. I have been registered for COS1511 or COS111U before but have never written the examination.
3. I have written the examination for COS1511 or COS111U once before.
4. I have written the examination for COS1511 or COS111U twice before.
5. I have written the examination for COS1511 or COS111U three or more times before.

Question 12 Have you drawn variable diagrams before enrolling for COS1511?

1. Yes
2. No

Question 13 Do you use the tutorial for this module while working through the study guide?

1. Yes
2. No

Question 14 Do you draw your own variable diagrams to help you to understand programs in the study guide?

1. Yes
2. No

Question 15 Do you draw your own variable diagrams to debug your programs?

1. Yes
2. No

Question 16 Up to now, how much time in total, have you spent using the tutorial?

1. Less than 1 hour
2. 1 to 3 hours
3. 4 to 6 hours
4. 7 to 8 hours
5. More than 8 hours

Question 17 To what degree did the tutorial assist you to master tracing?

1. Not at all
2. Neutral
3. A little bit
4. Fairly useful
5. Very useful

Question 18 Did you find it interesting to use the tutorial?

1. Not at all
2. Neutral
3. A little bit
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1. Not at all
2. Neutral
3. A little bit
4. Fairly motivating
5. Very motivating

Question 20 To what degree did you enjoy using the tutorial?

1. Not at all
2. Not really
3. Neutral
4. Moderately
5. Very much

Question 21 Did you find it irritating to use the tutorial?

1. Not at all
2. Neutral
3. A little bit
4. Fairly irritating
5. Very irritating

B.2 Questionnaires used in second implementation cycle

B.2.1 First semester 2013

B.2.1.1 First questionnaire

"Assignment 91" for COS1511-13-S1

Assignment 91 is a questionnaire to assist us in determining the usability and effectivenes of the Drawing variable Diagrams tutorial. Please complete Assignment 91 after you have submitted Assignment 1.

This assessment is **due Wednesday, 2013-Mar-27 11:25 AM**.

Choose only 1 option in each of the following questions:

1. Please select your gender?

a. Male
b. Female

2. What is your age?

a. 19 - 22
b. 23 - 27
c. 28 - 32
d. 32 – 40
e. 41 +

3. Which ONE of the following describes your situation best?

a. I am a full-time student who does not work at all.
b. I am a full-time student who works part-time for extra pocket money (not to pay for my studies).
c. I am a full-time student who works part-time to pay for my studies.
d. I work full-time and study after hours, and the work that I do is not related to my degree at all.
e. I work full-time and study after hours, and the work that I do is related to my degree
f. Other

4. My highest qualification is

a. Matric
b. National certificate
c. Diploma
d. Degree
e. Post-graduate degree

5. My first language is

a. English
b. Afrikaans
c. Other

6. If you do not have a South African matric please choose the option you think are most relevant to you. In my matric results

a. I passed Mathematics (higher grade) or equivalent with a C-symbol or higher.
b. I passed Mathematics (higher grade) or equivalent with a D-symbol or lower.
c. I passed Mathematics (standard grade) or equivalent with a C-symbol or higher.
d. I passed Mathematics (standard grade) or equivalent with a D-symbol or lower.

e. I did not take Mathematics for matric.

7. If you do not have a South African matric please choose the option you think are most relevant to you. In my matric results

a. I passed English (higher grade) or equivalent with a C-symbol or higher.
b. I passed English (higher grade) or equivalent with a D-symbol or lower.
c. I passed English (standard grade) or equivalent with a C-symbol or higher.
d. I passed English (standard grade) or equivalent with a D-symbol or lower.
e. I did not take English for matric.

8. Did you have Computer Applications Technology, Information Technology or Computer Studies at school?

a. Yes
b. No

9.
Please choose the option below that best describes your computer literacy level. If more than one option applies to you, choose the option that reflects your most recent computer literacy enrichment experience.

a. None
b. Self-taught
c. Did Computer Applications Technology, Information Technology or Computer Studies at school
d. Passed or enrolled for ICDL or EUP at Unisa
e. Done any other computer literacy course
f. Use a computer daily at work
g. Other means of exposure/experience towards computer literacy development

10.
What experience do you have in programming?

a. None
b. Computer Studies or Information Technology at school
c. Repeating COS1511
d. Currently enrolled for another programming module at Unisa
e. Did a programming course other than COS1511
f. Employed as a programmer
g. Other programming experience

11.
Which ONE of the following is applicable to you?

a. This is my first registration for COS1511.
b. I have been registered for COS1511 or COS111U before but have never written the examination.
c. I have written the examination for COS1511 or COS111U once before.
d. I have written the examination for COS1511 or COS111U twice before.
e. I have written the examination for COS1511 or COS111U three or more times before.

12.
Have you drawn variable diagrams before enrolling for COS1511?

a. Yes
b. No

13.
Do you use the Drawing Variable Diagrams tutorial for this module while working through the study guide?

a. Yes
b. No

14.
If you answered yes on the previous question, did you watch the Instructions to learn how to use the Drawing Variable Diagrams tutorial?

a. Yes
b. No

15.
If you answered yes on the previous question, did watching the Instructions to learn how to use the Drawing Variable Diagrams tutorial, help you?

a. Not at all
b. Not really
c. Undecided/Neutral
d. To some extent
e. Definitely

16.
Do you draw your own variable diagrams to help you to understand programs in the study guide?

a. Yes
b. No

17.
Do you draw your own variable diagrams to debug your programs?

a. Yes
b. No

18.
Do you feel that using variable diagrams improves your programming skills?

a. Not at all
b. Not really
c. Undecided/Neutral
d. To some extent
e. Definitely

19.
Do you feel that using variable diagrams assist with understanding the flow of logic in a program?

a. Not at all
b. Not really
c. Undecided/Neutral
d. To some extent
e. Definitely

20.
Did you use the Drawing Variable Diagrams tutorial before or while completing Assignment 1?

a. Yes
b. No

21.
Did you use the Drawing Variable Diagrams tutorial after you have submitted Assignment 1?
a. Not at all
b. Not really

22.
Up to now, how much time in total, have you spent using the Drawing Variable Diagrams tutorial?
a. Less than 1 hour
b. 1 to 10 hours
c. 11 to 20 hours
d. 20 to 30 hours
e. More than 30 hours

B.2.1.2 Second questionnaire

"Assignment 92" for COS1511-13-S1
Assignment 92 is now available as a self-assessment assignment. Please complete Assignment 92 even if you have submitted Assignment 91. If you have submitted Assignment 91, you may skip questions 2 to 12.

Assignment 92 is due on 26 May.

Assignment 92 is an optional questionnaire for research conducted by Mrs MA Schoeman (schoema@unisa.ac.za) and Prof JH Gelderblom on the usability and effectiveness of the Drawing Variable Diagrams tutorial. Both Assignment 91 and 92 are questionnaires to assist us in determining the usability and effectiveness of the Drawing Variable Diagrams tutorial.

This research is conducted under the following conditions:
• Participants are not personally being tested, and their participation will not impact in any way on their assessment in COS1511 assignments or the exam.
• There will be no monetary payment to the participants.
• Participants are free to withdraw from the research or not partake at all, and there will be no disadvantage if they do so.
• In reporting results of this study, no names will be disclosed. Research findings will be communicated at presentations or be published in academic publications, but anonymity and confidentiality will be preserved.
• By completing the questions in Assignment 92, you declare that you are aware of the above information and willingly partake in this research.
We appreciate your co-operation in this research.
Best wishes for your studies!
Regards
Mrs MA Schoeman

This assessment is **due Tuesday, 2013-May-07 03:11 PM**.

Please choose one option from each of the following questions.

1. Have you submitted Assignment 91? If you did, you may skip questions 2 to 12. Please complete all the rest of the questions.
a. Yes
b. No

2. Please select your gender?

a. Male
b. Female

3. What is your age?

a. 19 - 22
b. 23 - 27
c. 28 - 32
d. 32 – 40
e. 41 +

4. Which ONE of the following describes your situation best?

a. I am a full-time student who does not work at all.
b. I am a full-time student who works part-time for extra pocket money (not to pay for my studies).
c. I am a full-time student who works part-time to pay for my studies.
d. I work full-time and study after hours, and the work that I do is not related to my degree at all.
e. I work full-time and study after hours, and the work that I do is related to my degree
f. Other

5. My highest qualification is

a. Matric
b. National certificate
c. Diploma
d. Degree
e. Post-graduate degree

6. My first language is

a. English
b. Afrikaans
c. Other

7. If you do not have a South African matric please choose the option you think are most relevant to you. In my matric results

a. I passed Mathematics (higher grade) or equivalent with a C-symbol or higher.
b. I passed Mathematics (higher grade) or equivalent with a D-symbol or lower.
c. I passed Mathematics (standard grade) or equivalent with a C-symbol or higher.
d. I passed Mathematics (standard grade) or equivalent with a D-symbol or lower.
e. I did not take Mathematics for matric.

8. If you do not have a South African matric please choose the option you think are most relevant to you. In my matric results

a. I passed English (higher grade) or equivalent with a C-symbol or higher.
b. I passed English (higher grade) or equivalent with a D-symbol or lower.
c. I passed English (standard grade) or equivalent with a C-symbol or higher.
d. I passed English (standard grade) or equivalent with a D-symbol or lower.
e. I did not take English for matric.

9. Did you have Computer Applications Technology, Information Technology or Computer Studies at school?

a. Yes
b. No

10. Please choose the option below that best describes your computer literacy level. If more than one option applies to you, choose the option that reflects your most recent computer literacy enrichment experience.

a. None
b. Self-taught
c. Did Computer Applications Technology, Information Technology or Computer Studies at school
d. Passed or enrolled for ICDL or EUP at Unisa
e. Done any other computer literacy course
f. Use a computer daily at work
g. Other means of exposure/experience towards computer literacy development

11. What experience do you have in programming?

a. None
b. Computer Studies or Information Technology at school
c. Repeating COS1511
d. Currently enrolled for another programming module at Unisa
e. Did a programming course other than COS1511
f. Employed as a programmer
g. Other programming experience

12. Which ONE of the following is applicable to you?

a. This is my first registration for COS1511.
b. I have been registered for COS1511 or COS111U before but have never written the examination.
c. I have written the examination for COS1511 or COS111U once before.
d. I have written the examination for COS1511 or COS111U twice before.
e. I have written the examination for COS1511 or COS111U three or more times before.

13. Have you drawn variable diagrams before enrolling for COS1511?

a. Yes
b. No

14. Do you use the Drawing Variable Diagrams tutorial for this module while working through the study guide?

a. Yes
b. No

15. If you answered yes on the previous question, did you watch the Instructions to learn how to use the Drawing Variable Diagrams tutorial?

a. Yes
b. No

16. If you answered yes on the previous question, did watching the Instructions to learn how to use the Drawing Variable Diagrams tutorial, help you?

a. Not at all
b. Not really
c. Undecided/Neutral
d. To some extent
e. Definitely

17. Do you draw your own variable diagrams to help you to understand programs in the study guide?

a. Yes

b. No

18. Do you draw your own variable diagrams to debug your programs?

a. Yes
b. No

19. Do you feel that using variable diagrams improves your programming skills?

a. Not at all
b. Not really
c. Undecided/Neutral
d. To some extent
e. Definitely

20. Do you feel that using variable diagrams assist with understanding the flow of logic in a program?

a. Not at all
b. Not really
c. Undecided/Neutral
d. To some extent
e. Definitely

21. Did you use the Drawing Variable Diagrams tutorial before or while completing Assignment 1?

a. Yes
b. No

22. Did you use the Drawing Variable Diagrams tutorial after you have submitted Assignment 1?

a. Not at all
b. Not really

23. Up to now, how much time in total, have you spent using the Drawing Variable Diagrams tutorial?

a. Less than 1 hour
b. 1 to 10 hours
c. 11 to 20 hours
d. 20 to 30 hours
e. More than 30 hours

24. Did watching the Drawing Variable Diagrams tutorial, help you to understand if statements?

a. Not at all
b. Not really
c. Undecided/Neutral
d. To some extent
e. Definitely

25. Did watching the Drawing Variable Diagrams tutorial, help you to understand while loops?

a. Not at all
b. Not really
c. Undecided/Neutral
d. To some extent
e. Definitely

26. Did watching the Drawing Variable Diagrams tutorial, help you to understand nested if statements?

a. Not at all
b. Not really
c. Undecided/Neutral
d. To some extent
e. Definitely

27. Did watching the Drawing Variable Diagrams tutorial, help you to understand switch statements?

a. Not at all
b. Not really
c. Undecided/Neutral
d. To some extent
e. Definitely

28. Did watching the Drawing Variable Diagrams tutorial, help you to understand the difference between while loops and do … while loops?

a. Not at all
b. Not really
c. Undecided/Neutral
d. To some extent
e. Definitely

29. Did watching the Drawing Variable Diagrams tutorial, help you to understand what happens when a function is executed?

a. Not at all
b. Not really
c. Undecided/Neutral
d. To some extent
e. Definitely

30. Did watching the Drawing Variable Diagrams tutorial, help you to understand value parameters?

a. Not at all
b. Not really
c. Undecided/Neutral
d. To some extent
e. Definitely

31. Did watching the Drawing Variable Diagrams tutorial, help you to understand reference parameters?

a. Not at all
b. Not really
c. Undecided/Neutral
d. To some extent
e. Definitely

32. Did watching the Drawing Variable Diagrams tutorial, help you to understand the difference between value and reference parameters?

a. Not at all
b. Not really
c. Undecided/Neutral
d. To some extent
e. Definitely

33. Did watching the Drawing Variable Diagrams tutorial, help you to understand one-dimensional arrays?

a. Not at all
b. Not really
c. Undecided/Neutral
d. To some extent
e. Definitely

34. Did watching the Drawing Variable Diagrams tutorial, help you to understand two-dimensional arrays?

a. Not at all
b. Not really
c. Undecided/Neutral
d. To some extent
e. Definitely

35. Did watching the Drawing Variable Diagrams tutorial, help you to understand strings?

a. Not at all
b. Not really
c. Undecided/Neutral
d. To some extent
e. Definitely

36. Did watching the Drawing Variable Diagrams tutorial, help you to understand structs?

a. Not at all
b. Not really
c. Undecided/Neutral
d. To some extent
e. Definitely

37. To trace a program means to form a mental picture of what the program does and how it is done. To what degree did the Drawing Variable Diagrams tutorial assist you to master tracing?

a. Not at all
b. Not really
c. Undecided/Neutral
d. To some extent
e. Definitely

38. Did you find it interesting to use the Drawing Variable Diagrams tutorial?

a. Not at all
b. Not really
c. Undecided/Neutral
d. To some extent
e. Definitely

39. Did you find it motivating to use the Drawing Variable Diagrams tutorial?

a. Not at all
b. Not really
c. Undecided/Neutral
d. To some extent
e. Definitely

40. Did you enjoy using the Drawing Variable Diagrams tutorial?

a. Not at all

b. Not really
c. Undecided/Neutral
d. To some extent
e. Definitely

41. Did you find it frustrating to use the Drawing Variable Diagrams tutorial?
a. Not at all
b. Not really
c. Undecided/Neutral
d. To some extent
e. Definitely

42. Did you find the Drawing Variable Diagrams tutorial easy to use?
a. Not at all
b. Not really
c. Undecided/Neutral
d. To some extent
e. Definitely

43. Did you find that the Drawing Variable Diagrams tutorial is directly applicable to the programming assignments in the course?
a. Not at all
b. Not really
c. Undecided/Neutral
d. To some extent
e. Definitely

44. Do you think that you will apply the general concept of variable diagrams in future programming projects?
a. Not at all
b. Not really
c. Undecided/Neutral
d. To some extent
e. Definitely

B.2.2 Second semester 2013 (only questionnaire)

"Assignment 91" for COS1511-13-S2
Assignment 91 is an optional questionnaire for research conducted by Mrs MA Schoeman (schoema@unisa.ac.za) and Prof JH Gelderblom on the usability and effectiveness of the Drawing Variable Diagrams tutorial. Assignment 91 is a questionnaire to assist us in determining the usability and effectiveness of the Drawing Variable Diagrams tutorial.

This research is conducted under the following conditions:

- Participants are not personally being tested, and their participation will not impact in any way on their assessment in COS1511 assignments or the exam.
- There will be no monetary payment to the participants.
- Participants are free to withdraw from the research or not partake at all, and there will be no disadvantage if they do so.
- In reporting results of this study, no names will be disclosed. Research findings will be communicated at presentations or be published in academic publications, but anonymity and confidentiality will be preserved.

- By completing the questions in Assignment 91, you declare that you are aware of the above information and willingly partake in this research.

We appreciate your co-operation in this research.
Best wishes for your studies!
Regards
Mrs MA Schoeman

This assessment is **due Saturday, 2013-Oct-12 02:08 PM**.

Choose only 1 option in each of the following questions:

1. Please select your gender?

a. Male
b. Female

2.
What is your age?

a. 19 - 22
b. 23 - 27
c. 28 - 32
d. 32 – 40
e. 41 +

3. Which ONE of the following describes your situation best?

a. I am a full-time student who does not work at all.
b. I am a full-time student who works part-time for extra pocket money (not to pay for my studies).
c. I am a full-time student who works part-time to pay for my studies.
d. I work full-time and study after hours, and the work that I do is not related to my degree at all.
e. I work full-time and study after hours, and the work that I do is related to my degree
f. Other

4. My highest qualification is

a. Matric
b. National certificate
c. Diploma
d. Degree
e. Post-graduate degree

5. My first language is

a. English
b. Afrikaans
c. Other

6. If you do not have a South African matric please choose the option you think are most relevant to you. In my matric results

a. I passed Mathematics (higher grade) or equivalent with a C-symbol or higher.
b. I passed Mathematics (higher grade) or equivalent with a D-symbol or lower.
c. I passed Mathematics (standard grade) or equivalent with a C-symbol or higher.
d. I passed Mathematics (standard grade) or equivalent with a D-symbol or lower.
e. I did not take Mathematics for matric.

7. If you do not have a South African matric please choose the option you think are most relevant to you. In my matric results

a. I passed English (higher grade) or equivalent with a C-symbol or higher.
b. I passed English (higher grade) or equivalent with a D-symbol or lower.
c. I passed English (standard grade) or equivalent with a C-symbol or higher.
d. I passed English (standard grade) or equivalent with a D-symbol or lower.
e. I did not take English for matric.

8. Did you have Computer Applications Technology, Information Technology or Computer Studies at school?

a. Yes
b. No

9. Please choose the option below that best describes your computer literacy level. If more than one option applies to you, choose the option that reflects your most recent computer literacy enrichment experience.

a. None
b. Self-taught
c. Did Computer Applications Technology, Information Technology or Computer Studies at school
d. Passed or enrolled for ICDL or EUP at Unisa
e. Done any other computer literacy course
f. Use a computer daily at work
g. Other means of exposure/experience towards computer literacy development

10. What experience do you have in programming?

a. None
b. Computer Studies or Information Technology at school
c. Repeating COS1511
d. Currently enrolled for another programming module at Unisa
e. Did a programming course other than COS1511
f. Employed as a programmer
g. Other programming experience

11. Which ONE of the following is applicable to you?

a. This is my first registration for COS1511.
b. I have been registered for COS1511 or COS111U before but have never written the examination.
c. I have written the examination for COS1511 or COS111U once before.
d. I have written the examination for COS1511 or COS111U twice before.
e. I have written the examination for COS1511 or COS111U three or more times before.

12.

Have you drawn variable diagrams before enrolling for COS1511?

a. Yes
b. No

13. Do you use the Drawing Variable Diagrams tutorial for this module while working through the study guide?

a. Yes
b. No

14. If you answered yes on the previous question, did you watch the Instructions to learn how to use the Drawing Variable Diagrams tutorial?

a. Yes
b. No

15. If you answered yes on the previous question, did watching the Instructions to learn how to use the Drawing Variable Diagrams tutorial, help you?

a. Not at all
b. Not really
c. Undecided/Neutral
d. To some extent
e. Definitely

16. Do you draw your own variable diagrams to help you to understand programs in the study guide?

a. Yes
b. No

17. Do you draw your own variable diagrams to debug your programs?

a. Yes
b. No

18. Do you feel that using variable diagrams improves your programming skills?

a. Not at all
b. Not really
c. Undecided/Neutral
d. To some extent
e. Definitely

19. Do you feel that using variable diagrams assist with understanding the flow of logic in a program?

a. Not at all
b. Not really
c. Undecided/Neutral
d. To some extent
e. Definitely

20. Did you use the Drawing Variable Diagrams tutorial before or while completing Assignment 1?

a. Yes
b. No

21. Did you use the Drawing Variable Diagrams tutorial after you have submitted Assignment 1?

a. Not at all
b. Not really

22. Up to now, how much time in total, have you spent using the Drawing Variable Diagrams tutorial?

a. Less than 1 hour
b. 1 to 10 hours
c. 11 to 20 hours
d. 20 to 30 hours
e. More than 30 hours

23. Did watching the Drawing Variable Diagrams tutorial, help you to understand if statements?

a. Not at all
b. Not really
c. Undecided/Neutral
d. To some extent
e. Definitely

24. Did watching the Drawing Variable Diagrams tutorial, help you to understand while loops?

a. Not at all
b. Not really
c. Undecided/Neutral
d. To some extent
e. Definitely

25. Did watching the Drawing Variable Diagrams tutorial, help you to understand nested if statements?

a. Not at all
b. Not really
c. Undecided/Neutral
d. To some extent
e. Definitely

26. Did watching the Drawing Variable Diagrams tutorial, help you to understand switch statements?

a. Not at all
b. Not really
c. Undecided/Neutral
d. To some extent
e. Definitely

27. Did watching the Drawing Variable Diagrams tutorial, help you to understand the difference between while loops and do … while loops?

a. Not at all
b. Not really
c. Undecided/Neutral
d. To some extent
e. Definitely

28. Did watching the Drawing Variable Diagrams tutorial, help you to understand what happens when a function is executed?

a. Not at all
b. Not really
c. Undecided/Neutral
d. To some extent
e. Definitely

29. Did watching the Drawing Variable Diagrams tutorial, help you to understand value parameters?

a. Not at all
b. Not really
c. Undecided/Neutral
d. To some extent
e. Definitely

30. Did watching the Drawing Variable Diagrams tutorial, help you to understand reference parameters?

a. Not at all
b. Not really
c. Undecided/Neutral
d. To some extent
e. Definitely

31. Did watching the Drawing Variable Diagrams tutorial, help you to understand the difference between value and reference parameters?

a. Not at all
b. Not really
c. Undecided/Neutral
d. To some extent
e. Definitely

32. Did watching the Drawing Variable Diagrams tutorial, help you to understand one-dimensional arrays?

a. Not at all
b. Not really
c. Undecided/Neutral
d. To some extent
e. Definitely

33. Did watching the Drawing Variable Diagrams tutorial, help you to understand two-dimensional arrays?

a. Not at all
b. Not really
c. Undecided/Neutral
d. To some extent
e. Definitely

34. Did watching the Drawing Variable Diagrams tutorial, help you to understand strings?

a. Not at all
b. Not really
c. Undecided/Neutral
d. To some extent
e. Definitely

35. Did watching the Drawing Variable Diagrams tutorial, help you to understand structs?

a. Not at all
b. Not really
c. Undecided/Neutral
d. To some extent
e. Definitely

36. To trace a program means to form a mental picture of what the program does and how it is done. To what degree did the Drawing Variable Diagrams tutorial assist you to master tracing?

a. Not at all
b. Not really
c. Undecided/Neutral
d. To some extent
e. Definitely

37. Did you find it interesting to use the Drawing Variable Diagrams tutorial?

a. Not at all
b. Not really
c. Undecided/Neutral
d. To some extent
e. Definitely

38. Did you find it motivating to use the Drawing Variable Diagrams tutorial?

a. Not at all
b. Not really
c. Undecided/Neutral
d. To some extent
e. Definitely

39. Did you enjoy using the Drawing Variable Diagrams tutorial?

a. Not at all
b. Not really
c. Undecided/Neutral
d. To some extent
e. Definitely

40. Did you find it frustrating to use the Drawing Variable Diagrams tutorial?

a. Not at all
b. Not really
c. Undecided/Neutral
d. To some extent
e. Definitely

41. Did you find the Drawing Variable Diagrams tutorial easy to use?

a. Not at all
b. Not really
c. Undecided/Neutral
d. To some extent
e. Definitely

42. Did you find that the Drawing Variable Diagrams tutorial is directly applicable to the programming assignments in the course?

a. Not at all
b. Not really
c. Undecided/Neutral
d. To some extent
e. Definitely

43. Do you think that you will apply the general concept of variable diagrams in future programming projects?

a. Not at all
b. Not really
c. Undecided/Neutral
d. To some extent
e. Definitely

B.3 Comparison between questionnaires used in first and second implementation cycles

Table B.3.1 Comparison between questionnaires, showing adaptions and extensions used in the second implementation cycle

	Question	Questionnaire Sem 1 2012	Questionnaire 1 sem 1 2013	Questionnaire 2 sem 1 2013	Questionnaire Sem 2 2013
				1 Submitted 1st questionnaire?	
Biographical detail	Gender	1	1	2	1
	Age	2	2	3	2
	Full /part-time	3	3 + option 'other'	4	3
	Highest qualifi	4	4	5	4
	1st language	5	5	6	5
	Maths	6	6	7	6
	English	7	7	8	7
	IT at school	8	8	9	8
	Computer literacy	9	9+ options 'none' & 'other'	10	9
Profile score, programming experience and using VDs*	Programming experience	10	10+ options 'none' & 'other'	11	10
Profile score	1st reg COS1511	11	11	12	11
Using VDs	VDs before?	12	12	13	12
Manner of tutorial use	Use tutorial?	13	13	14	13
			14 Watch instructions?	15	14
			15 Instructions help?	16	15
Using VDs	Own VD to understand programs	14	16	17	16
	Own VD to debug	15	17	18	17
Learning from tutorial			18 VDs improve programming skill?	19	18
			19 VDs assist logic?	20	19
Manner of tutorial use				21 Use tut** to do asg 1***	20
				22 Use tut after submit asg 1	21
	Time spent using tutorial	16	20	23 **NB Times differ from 1st questionnaire**	22 **Correspond to 2nd questionnaire sem 1 2013**
Learning from tutorial				24 Help understand `if`	23
				25 Help understand `while`	24
				26 Help understand	25

				nested `ifs`	
				27Help understand `switch`	26
Learning from tutorial				28 Help understand diff `while` & `do while`	27
				29 Help understand function execution	28
				30 Help understand value parameters	29
				31 Help understand reference parameters	30
				32 Help understand difference between value & ref parameters	31
				33 Help understand 1 dim arrays	32
				34 Help understand 2 dim arrays	33
				35 Help understand strings	34
				36 Help understand `structs`	35
	Tut help master tracing?	17	21 +explain tracing	37	36
Positive user experience Positive user experience	Interesting to use tut?	18	22	38	37
	Motivating to use tut?	19	23	39	38
	Enjoy using tut?	20	24	40	39
	Irritating to use tut?	21	25 'frustrating' instead of 'irritating'	41	40
			26 Tut easy to use?	42	41
Learning from tutorial			27 Applicable to assignments?	43	42
			28 Apply VDs in future?	44	43

Legend: *VD – variable diagram;tut – tutorial; ***asg – assignment**

Appendix C Documentation used for eye tracking and observation in HCI laboratory

C.1 E-mail request to participate in research

Request to participate in research

Dear Student

We are conducting research on the usability and effectiveness of the tutorial to teach tracing for COS1511. In particular, we want to determine how easy it is to use the tutorial and how to improve it. We need volunteers to observe while they use the tutorial in the Human Computer Interaction laboratory at the Muckleneuk Campus of Unisa in Pretoria.

Each session will take approximately 1 to 1½ hours, and you would only do one session. We would like you to work though lesson 1 to 11 of the Study Guide for COS1511 beforehand, though it is not necessary to do the activities for those lessons in the tutorial to teach tracing, beforehand.

The research is conducted under the following conditions:

- Participants are not personally being tested, and their participation will not impact in any way on their assessment in COS1511 assignments or the exam.
- There will be no monetary payment to the participants.
- Participants are free to withdraw from the research or not partake at all, and there will be no disadvantage if they do so.
- In reporting results of this study, no names will be disclosed. Research findings will be communicated at presentations or be published in academic publications, but anonymity and confidentiality will be preserved.

If you are willing to participate on 2, 3 or 8 August, please contact Mrs Schoeman at the following e-mail address schoema@unisa.ac.za. Please include your student number and cell phone number in the e-mail so that we can arrange a suitable time.

C.2 Informed consent form

Thank you for volunteering as a participant in this research on the usability and effectiveness of the tutorial to teach tracing for the module, COS1511

Mrs MA Schoeman (schoema@unisa.ac.za; tel 012 429 6857) and prof JH Gelderblom (geldejh@unisa.ac.za; tel 012 429 6631) are conducting research on the usability and effectiveness of the *Tutorial to teach tracing* software which is supplementary study material for the module COS1511.

The research is conducted under the following conditions:

- Participants are not personally being tested, and their participation in this study will not impact in any way on their assessment in COS1511 assignments or the exam.
- There will be no monetary payment to participants.
- Participants are free to withdraw from the research and there will be no disadvantage if they do so.
- In reporting results of this study, no names will be disclosed. Research findings will be communicated at presentations or be published in academic publications, but anonymity and confidentiality will be preserved.

I (full name) ____

Contact details ____

declare that I am aware of all the information provided above and have willingly served as a participant in the research on the *Tutorial to teach tracing*. I am aware that the findings of this study might be published in academic sources, but that my name will not be disclosed.

on ………………… at ………………………………………..

Date Place

…………………………
Signature

C.3 Task List for usability testing of Drawing Variable Diagrams tutorial

Task 1:
Draw variable diagrams for Program 1.

Task 2:
Do the following activities in the Drawing Variable Diagrams tutorial:
Activity 3.a.i
Activity 4.a.ii
Activity 4.b

Task 3:
Do exercise at end of Activity 4.b.

Task 4:
Activity 5.a
Activity 8.a.iii
Activity 9.a.v

Task 5:
Draw variable diagrams for program 2.

Task 6:
Complete interview questions.

Program 1:

```
#include <iostream>
using namespace std;

int main()
{
    int a,b,c;
    a = 0;
    b = 0;
    cout << "Enter a number: ";
    cin >> c;
    while (c != 0)
    {
        if (c > 0)
            a = a + c;
        else b = b + c;
        cout << "Enter a number: ";
        cin >> c;
    }

    cout << "a = " << a << endl;
    cout << "b = " << b << endl;
    return 0;
}
```

Input:

```
5   9   -4   3    -9    0
```

Program 2:

```
#include <iostream>
using namespace std;

int main()
{
    int a,b,c;
    a = 0;
    b = 0;
    cout << "Enter a number: ";
    cin >> c;
    while (c > 0)
    {
        if (c % 2 == 0)
            a += c;
        else b += c;
        cout << "Enter a number: ";
        cin >> c;
    }

    cout << "a = " << a << endl;
    cout << "b = " << b << endl;
    return 0;
}
```

Input:

```
5  2  4  88  11  0
```

C.4 Interview questions for the Drawing Variable Diagrams Research Project

Participant ____

Age ____________ Gender ____________ Date ____________

First language ____

1. Are you computer literate, i.e. did you do Computer Science at school, EUP1501, a course or taught yourself ?

____

2. Have you drawn variable diagrams before?__________

If Yes, Where did you learn to do it?

____

3. Have you used the e-learning tutorial, Drawing Variable Diagrams before today?__________

4. If you have drawn variable diagrams before, did you find it easier to do now that you have used the tutorial? Why/ why not?

____

____

5. Do you draw your own variable diagrams to help you to understand programs in the study guide?

____

6. Did the questions in the activities help you to concentrate, think or understand drawing variable diagrams?

____

7. Would you like to have sound / someone explaining how to do it while using the tutorial?

____

8. What would you change?

____

____

____

9. Were there any weaknesses in Drawing Variable Diagrams or things in Drawing Variable Diagrams that confused you?
Yes/No/not sure_______________

10. If so, please tell us about them

____

11. What   you think about your experience with the Drawing Variable Diagrams tutorial?

____

____

12. Were you put off by working in the usability lab, being observed? ____________________

13. Is there anything else you would like to tell us?

____

____

Thank you for taking part. We really appreciate it!

Appendix D Supporting statistical figures and tables

D.1 First implementation cycle 2012 of the Drawing Variable Diagrams Tutorial

D.1.1. Final marks for 2012 examinations (section 6.2.1)

Table D.1.1 Quantiles for final marks for respondents for both semesters 2012

		Semester 1	Semester 2
100.0%	maximum	100	97.78
99.5%		98.2554	97.04185
97.5%		93.386	92.22
90.0%		86.89	79.832
75.0%	quartile	70	59.44
50.0%	median	48.89	38.33
25.0%	quartile	22.78	23.33
10.0%		12.78	13.33
2.5%		4.44	8.89
0.5%		1.5318	5.56
0.0%	minimum	0	5.56

Table D.1.2 Summary statistics for final marks for respondents for both semesters 2012

	Semester 1	Semester 2
Mean	47.453768	42.382011
Std Dev	27.245998	23.648602
Std Err Mean	1.2501321	1.0252969
Upper 95% Mean	49.910255	44.396147
Lower 95% Mean	44.997282	40.367875
N	475	532
Skewness	0.1321734	0.5275374
Kurtosis	-1.238815	-0.688703

D.1.2 The effect of the ability to explain the purpose of code (question 1) on a student's final mark (section 6.2.2)

Table D.1.3 Multivariate correlations for questions 1 to 8 in Part B of the first semester 2012 examination paper

	Q1%	Q2%	Q3%	Q4%	Q5%	Q6%	Q7%	Q8%
Q1%	1.0000	0.5396	0.5619	0.5529	0.5298	0.4922	0.4196	0.4284
Q2%	0.5396	1.0000	0.6232	0.6831	0.6969	0.5940	0.5808	0.5087
Q3%	0.5619	0.6232	1.0000	0.7126	0.6991	0.6052	0.6259	0.4803
Q4%	0.5529	0.6831	0.7126	1.0000	0.7728	0.6480	0.6050	0.4953
Q5%	0.5298	0.6969	0.6991	0.7728	1.0000	0.7417	0.6832	0.5626
Q6%	1.0000	0.5396	0.5619	0.5529	0.5298	0.4922	0.4196	0.4284
Q7%	0.5396	1.0000	0.6232	0.6831	0.6969	0.5940	0.5808	0.5087
Q8%	0.5619	0.6232	1.0000	0.7126	0.6991	0.6052	0.6259	0.4803

Table D.1.4 Multivariate correlations for questions 1 to 8 in Part B of the second semester 2012 examination paper

	Q1 %	Q2 %	Q3 %	Q4 %	Q5 %	Q6 %	Q7 %	Q8 %
Q1 %	1.0000	0.4176	0.3649	0.4741	0.4798	0.3088	0.3495	0.2944
Q2 %	0.4176	1.0000	0.5670	0.6113	0.6583	0.5194	0.5179	0.4909
Q3 %	0.3649	0.5670	1.0000	0.6239	0.6217	0.5691	0.5506	0.4197
Q4 %	0.4741	0.6113	0.6239	1.0000	0.7019	0.6068	0.5929	0.5138
Q5 %	0.4798	0.6583	0.6217	0.7019	1.0000	0.7097	0.6522	0.5771
Q6 %	0.3088	0.5194	0.5691	0.6068	0.7097	1.0000	0.7544	0.6473
Q7 %	0.3495	0.5179	0.5506	0.5929	0.6522	0.7544	1.0000	0.6689
Q8 %	0.2944	0.4909	0.4197	0.5138	0.5771	0.6473	0.6689	1.0000

Table D.1.5 Analysis of variance for linear regression question 1 on PM% semester 1 2012

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	146165.17	146165	336.0918
Error	473	205706.07	435	Prob > F
C. Total	474	351871.25		<.0001*

Table D.1.6 Summary of fit for linear regression question 1 on PM% semester 1 2012

RSquare	0.415394
RSquare Adj	0.414158
Root Mean Square Error	20.85417
Mean of Response	47.45377
Observations (or Sum Wgts)	475

Table D.1.7 Analysis of variance for linear regression question 1 on PM% semester 2 2012

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	78291.68	78291.7	189.7560
Error	530	218673.44	412.6	Prob > F
C. Total	531	296965.13		<.0001*

Table D.1.8 Summary of fit for linear regression question 1 on PM% semester 2 2012

RSquare	0.263639
RSquare Adj	0.26225
Root Mean Square Error	20.31235
Mean of Response	42.38201
Observations (or Sum Wgts)	532

D.1.3 The effect of the ability to trace (question 2) on a student's final mark (section 6.2.3)

Table D.1.9 Analysis of variance for linear regression question 2 on PM% semester 1 2012

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	237045.08	237045	976.4527
Error	473	114826.17	243	Prob > F
C. Total	474	351871.25		<.0001*

Table D.1.10 Summary of fit for linear regression question 2 on PM% semester 1 2012

RSquare	0.67367
RSquare Adj	0.67298
Root Mean Square Error	15.5808
Mean of Response	47.45377
Observations (or Sum Wgts)	475

Table D.1.11 Analysis of variance for linear regression question 2 on PM% semester 2 2012

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	180889.21	180889	825.9361
Error	530	116075.91	219	Prob > F
C. Total	531	296965.13		<.0001*

Table D.1.12 Summary of fit for linear regression question 2 on PM% semester 2 2012

RSquare	0.609126
RSquare Adj	0.608389
Root Mean Square Error	14.79903
Mean of Response	42.38201
Observations (or Sum Wgts)	532

D.1.4 The combined effect of effect of the ability to explain code and the ability to trace (questions 1 and 2) on a student's final mark (section 6.2.4)

Semester 1 2012

Table D.1.13 Analysis of variance for combined effect of question 1 and question 2 on PM% semester 1 2012

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	258485.11	86161.7	434.5630
Error	471	93386.13	198.3	Prob > F
C. Total	474	351871.25		<.0001*

Table D.1.14 Measure of fit for combined effect of question 1 and question 2 on PM% semester 1 2012

RSquare	0.734601
RSquare Adj	0.732911
Root Mean Square Error	14.08091
Mean of Response	47.45377
Observations (or Sum Wgts)	475

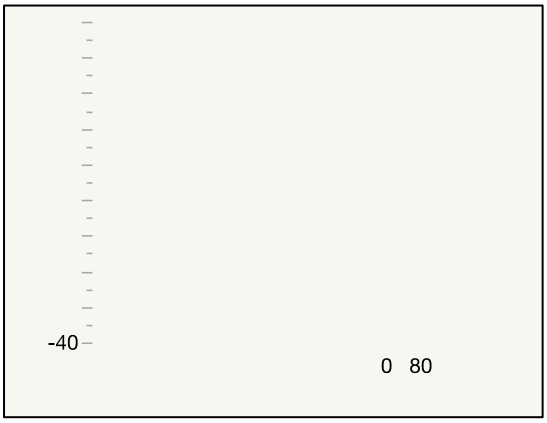


Figure D.1.1 Residual by predicted plot for the combined effect of question 1 and question 2 on PM% semester 1 2012

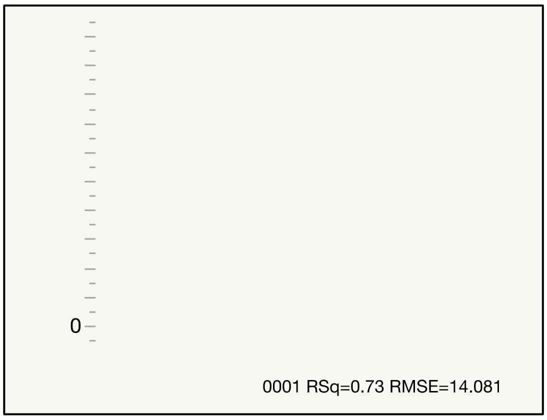


Figure D.1.2 Actual by predicted plot for the combined effect of question1 and question 2 on PM% semester 1 2012

Semester 2 1012

Table D.1.15 Analysis of variance for the combined effect of question 1 and question 2 on PM% semester 2 2012

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	3	195894.24	65298.1	341.1209
Error	528	101070.88	191.4	Prob > F
C. Total	531	296965.13		<.0001*

Table D.1.16 Measure of fit for combined effect of question 1 and question 2 on PM% semester 2 2012

RSquare	0.659654
RSquare Adj	0.65772
Root Mean Square Error	13.83554
Mean of Response	42.38201
Observations (or Sum Wgts)	532

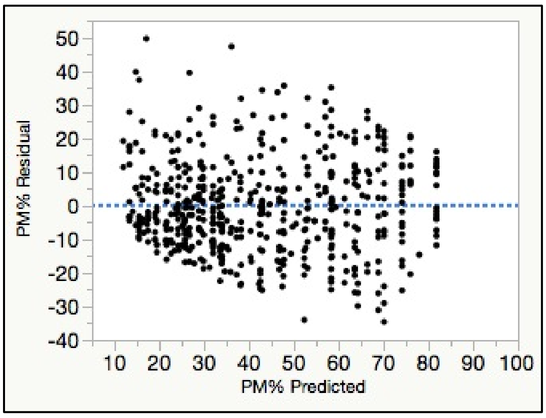


Figure D.1.3 Residual by predicted plot for the combined effect of question 1 and question 2 on PM% semester 2 2012

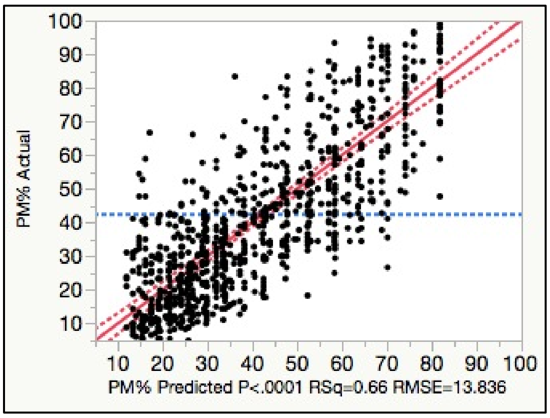


Figure D.1.4 Actual by predicted plot for the combined effect of question 1 and question 2 on PM% semester 2 2012

D.1.5 Biographical detail and descriptive statistics (section 6.3.2)

Table D.1.17 Biographical data of students in first semester of 2012

Q1 Gender?	**N**	**% of Total**
1. Male	353	74.32%
2. Female	122	25.68%
All	475	100.00%
Q2 What is your age?		
1. 19 - 22	27	5.68%
2. 23 - 27	224	47.16%
3. 28 - 32	129	27.16%
4. 32 – 40	80	16.84%
5. 41 +	15	3.16%
All	475	100.00%
Q3 Which ONE of the following describes your situation best?		
1. I am a full-time student who does not work at all.	64	13.47%
2. I am a full-time student who works part-time for extra pocket money (not to pay for my studies).	30	6.32%
3. I am a full-time student who works part-time to pay for my studies.	30	6.32%
4. I work full-time and study after hours, and the work that I do is not related to my degree at all.	136	28.63%
5. I work full-time and study after hours, and the work that I do is related to my degree	215	45.26%
All	475	100.00%
Q4 My highest qualification is		
1. Matric	247	52.00%
2. National certificate	95	20.00%
3. Diploma	98	20.63%
4. Degree	27	5.68%
5. Post-graduate degree	8	1.68%
All	475	100.00%
Q5 My first language is		
1. English	161	33.89%
2. Afrikaans	96	20.21%
3. Other	218	45.89%
All	475	100.00%
Q6 In my Matric results		
1. I passed Mathematics (higher grade) or equivalent with a C-symbol or higher.	95	20.00%
2. I passed Mathematics (higher grade) or equivalent with a D-symbol or lower.	74	15.58%
3. I passed Mathematics (standard grade) or equivalent with a C-symbol or higher.	125	26.32%
4. I passed Mathematics (standard grade) or equivalent with a D-symbol or lower.	176	37.05%
5. I did not take Mathematics for matric.	5	1.05%
All	475	100.00%
Q7 In my Matric results		
1. I passed English (higher grade) or equivalent with a C-symbol or higher.	221	46.53%
2. I passed English (higher grade) or equivalent with a D-symbol or lower.	206	43.37%
3. I passed English (standard grade) or equivalent with a C-symbol or higher.	15	3.16%
4. I passed English (standard grade) or equivalent with a D-symbol or lower.	33	6.95%
All	475	100.00%
Q8 Did you have Computer Applications Technology, Information Technology or Computer Studies at school?		
1 Yes	183	38.53%
2 No	292	61.47%
All	475	100.00%
Q9 What level of computer literacy do you have? If you have done more than one, choose the option reflecting the most recent one you have done.		
Self-taught	79	16.63%
Did Computer Applications Technology, Information Technology or Computer Studies at	58	12.21%

school		
Passed or enrolled for ICDL or EUP at Unisa	83	17.47%
Done any other computer literacy course	88	18.53%
Use a computer daily at work	167	35.16%
All	475	100.00%

Table D.1.18 Biographical data of students in second semester of 2012

Q1 Gender?	**N**	**% of Total**
1. Male	370	69.55%
2. Female	162	30.45%
All	532	100.00%
Q2 What is your age?		
1. 19 - 22	177	33.27%
2. 23 - 27	180	33.83%
3. 28 - 32	90	16.92%
4. 32 – 40	72	13.53%
5. 41 +	13	2.44%
All	532	100.00%
Q3 Are you studying full-time or part-time?		
1 Full-time	172	33.08%
2 Part-time	348	66.92%
All	520	100.00%
Q4 What is your occupation?		
1. Unemployed	139	26.27%
2. Full-time student	84	15.87%
3. IT-related	130	24.57%
4. Other	176	33.29%
All	529	100%
Q5 What is your highest qualification?		
1. Matric	340	63.91%
2. National certificate	75	14.10%
3. Diploma	84	15.79%
4. Degree	24	4.51%
5. Post-graduate degree	9	1.69%
All	532	100.00%
Q6 What is your first language?		
1. English	206	38.94%
2. Afrikaans	89	16.82%
3. Other	234	44.248%
All	529	100.00%
Q7 Did you have Computer Applications Technology, Information Technology or Computer Studies at school?		
1 Yes	239	45.09%
2 No	291	54.91%
All	530	100.00%
Q8 Have you been registered for COS1511 before?		
1 Yes	227	42.91%
2 No	302	57.09%
All	529	100.00%
Q9 What level of computer literacy do you have? If you have done more than one, choose the option reflecting the most recent one you have done.		
Self-taught	108	20.30%
Did Computer Applications Technology, Information Technology or Computer Studies at school	80	15.04%
Passed or enrolled for ICDL or EUP at Unisa	140	26.32%
Done any other computer literacy course	85	15.98%
Use a computer daily at work	119	22.36%
All	532	100.00%

D.1.5 English and Mathematics marks (section 6.3.3.1)

Table D.1.19 Quantiles for Mathematics marks for respondents for both semesters 2012

		Semester 1	Semester 2
100.0%	maximum	91	93
99.5%		87.24	90.67
97.5%		80	80
90.0%		70	72.7
75.0%	quartile	60	60
50.0%	median	50	50
25.0%	quartile	40	40
10.0%		33	33
2.5%		33	27.975
0.5%		28.14	13.665
0.0%	minimum	10	10

Table D.1.20 Summary statistics for Mathematics marks for respondents for both semesters 2012

	Semester 1	Semester 2
Mean	51.517895	51.62406
Std Dev	14.488071	15.572975
Std Err Mean	0.6647583	0.6751741
Upper 95% Mean	52.824132	52.9504
Lower 95% Mean	50.211657	50.29772
N	475	532
Skewness	0.4479225	0.3308532
Kurtosis	-0.600023	-0.5953

Table D.1.21 Quantiles for English marks for respondents for both semesters 2012

		Semester 1	Semester 2
100.0%	maximum	89	90
99.5%		80	83.675
97.5%		80	80
90.0%		70	70
75.0%	quartile	60	60
50.0%	median	50	50
25.0%	quartile	40	47
10.0%		40	40
2.5%		33	33
0.5%		31.14	31.995
0.0%	minimum	30	30

Table D.1.22 Summary statistics for English marks for respondents for both semesters 2012

	Semester 1	Semester 2
Mean	53.052632	54.231203
Std Dev	12.039815	11.923529
Std Err Mean	0.5524246	0.5169506
Upper 95% Mean	54.138136	55.246722
Lower 95% Mean	51.967128	53.215684
N	475	532
Skewness	0.3562772	0.3732152
Kurtosis	-0.412812	-0.434236

D.1.6 Positive user experience (questions 17 to 21) (section 6.3.3.3).

Table D.1.23 Quantiles for positive user experience for both semesters 2012 all respondents

		Semester 1	Semester 2
100.0%	maximum	5	5
99.5%		5	5
97.5%		5	5
90.0%		5	4.8
75.0%	quartile	4.4	4.4
50.0%	median	3.8	3.8
25.0%	quartile	3.2	3
10.0%		2.6	2.6
2.5%		1.78	1.8
0.5%		1	1.131
0.0%	minimum	1	1

Table D.1.24 Summary statistics for positive user experience for both semesters 2012 all respondents

	Semester 1	Semester 2
Mean	3.7511579	3.680283
Std Dev	0.8951662	0.8948144
Std Err Mean	0.041073	0.0388683
Upper 95% Mean	3.8318657	3.7566381
Lower 95% Mean	3.6704501	3.6039279
N	475	530
Skewness	-0.569449	-0.397598
Kurtosis	-0.133829	-0.490948

Table D.1.25 Cronbach's coefficient alpha for positive user experience semester 1 2012

Excluded Col	**α**
Q17 To what degree did the tutorial assist you to master tracing?	0.8634
Q18 Did you find it interesting to use the tutorial?	0.8268
Q19 Did you find it motivating to use the tutorial?	0.8241
Q20 To what degree did you enjoy using the tutorial?	0.8403
Q21 Did you find it irritating to use the tutorial? 2	0.9122
Entire set	0.8824

Table D.1.26 Cronbach's coefficient alpha for positive user experience semester 2 2012

Excluded Col	α
Q16 Up to now, how much time in total, have you spent using the tutorial?	0.8750
Q17 To what degree did the tutorial assist you to master tracing?	0.7792
Q18 Did you find it interesting to use the tutorial?	0.7555
Q19 Did you find it motivating to use the tutorial?	0.7596
Q20 To what degree did you enjoy using the tutorial?	0.7883
Q21 Did you find it irritating to use the tutorial? 4	0.8487
Entire set	0.8323

D.1.7 First semester 2012 model on all the data for relationships between the final mark (PM%) and the factors that could possibly influence it (section 6.3.4.1)

Table D.1.27 Analysis of variance for the full model for the relationship between PM% and the factors that could influence it for semester 1 2012

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	14	155250.14	11089.3	25.9437
Error	460	196621.11	427.4	Prob > F
C. Total	474	351871.25		<.0001*

Table D.1.28 Measure of fit for the full model for the relationship between PM% and the factors that could influence it for semester 1 2012

RSquare	0.441213
RSquare Adj	0.424206
Root Mean Square Error	20.67455
Mean of Response	47.45377
Observations (or Sum Wgts)	475

Table D.1.29 Analysis of variance for the final model for the relationship between PM% and the factors that could influence it for semester 1 2012

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	8	151379.83	18922.5	43.9813
Error	466	200491.41	430.2	Prob > F
C. Total	474	351871.25		<.0001*

Table D.1.30 Measure of fit for the final model for the relationship between PM% and the factors that could influence it for semester 1 2012

RSquare	0.430214
RSquare Adj	0.420432
Root Mean Square Error	20.74221
Mean of Response	47.45377
Observations (or Sum Wgts)	475

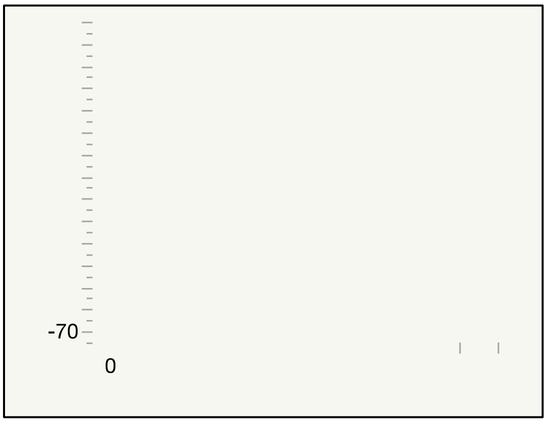


Figure D.1.5 Residual by predicted plot for the final model for the relationship between PM% and the factors that could influence it for semester 1 2012

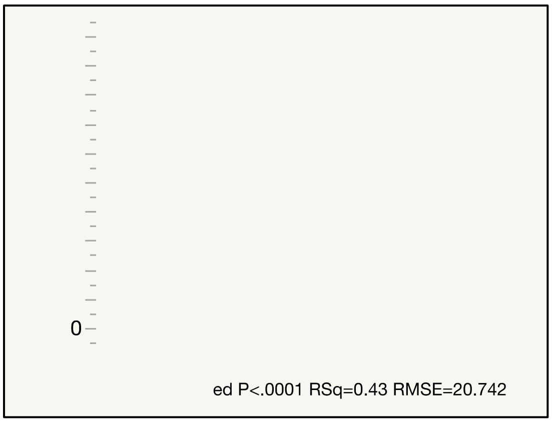


Figure D.1.6 Actual by predicted plot for the final model for the relationship between PM% and the factors that could influence it for semester 1 2012

D.1.8 Second semester 2012 model on all the data for relationships between the final mark (PM%) and the factors that could possibly influence it (section 6.3.4.1)

Table D.1.31 Analysis of variance for the full model for the relationship between PM% and the factors that could influence it for semester 2 2012

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	12	103265.11	8605.43	23.2767
Error	517	191135.17	369.70	Prob > F
C. Total	529	294400.28		<.0001*

Table D.1.32 Measure of fit for the full model for the relationship between PM% and the factors that could influence it for semester 2 2012

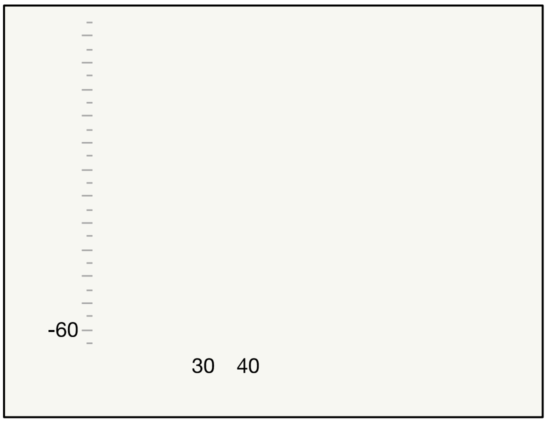
RSquare	0.350764
RSquare Adj	0.335695
Root Mean Square Error	19.2276
Mean of Response	42.25683
Observations (or Sum Wgts)	530

Table D.1.33 Analysis of variance for the final model for the relationship between PM% and the factors that could influence it for semester 2 2012

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	7	102866.79	14695.3	39.6722
Error	524	194098.33	370.4	Prob > F
C. Total	531	296965.13		<.0001*

Table D.1.34 Measure of fit for the final model for the relationship between PM% and that the factors that could influence it for semester 2 2012

RSquare	0.346394
RSquare Adj	0.337662
Root Mean Square Error	19.24621
Mean of Response	42.38201
Observations (or Sum Wgts)	532



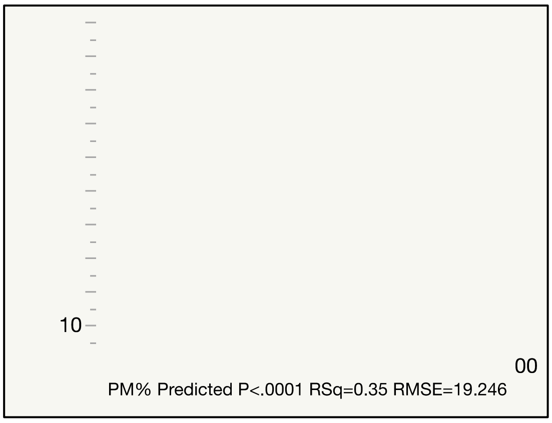


Figure D.1.7 Residual by predicted plot for the final model for the relationship between PM% and that the factors that could influence it semester 2 2012

Figure D.1.8 Actual by predicted plot for the final model for the relationship between PM% and that the factors that could influence it semester 2 2012

D.1.9 Relationship between time spent using tutorial (Q16) and PM% (section 6.3.4.4)

Semester 1 1012

Table D.1.35 Analysis of variance for PM% by time spent using the tutorial for semester 1 2012

Source	DF	Sum of Squares	Mean Square	F Ratio
Q16 Up to now, how much time in total, have you spent using the tutorial?	4	20551.26	5137.81	7.2883
Error	470	331319.99	704.94	
C. Total	474	351871.25		

Table D.1.36 Measure of fit for PM% by time spent using the tutorial for semester 1 2012

RSquare	0.058406
RSquare Adj	0.050392
Root Mean Square Error	26.55063
Mean of Response	47.45377
Observations (or Sum Wgts)	475

Semester 2 1012

Table D.1.37 Analysis of variance for PM% by time spent using the tutorial for semester 2 2012

Source	DF	Sum of Squares	Mean Square	F Ratio
Q16 Up to now, how much time in total, have you spent using the tutorial?	4	10468.47	2617.12	4.8116
Error	526	286102.36	543.92	
C. Total	530	296570.84		

Table D.1.38 Measure of fit for PM% by time spent using the tutorial for semester 2 2012

RSquare	0.035298
RSquare Adj	0.027962
Root Mean Square Error	23.32211
Mean of Response	42.34465
Observations (or Sum Wgts)	531

D.1.10 Relationship between programming experience (Q10) and PM% (section 6.3.4.5)

Semester 1 1012

Table D.1.39 Analysis of variance for PM% by programming experience for semester 1 2012

Source	DF	Sum of Squares	Mean Square	F Ratio
Q10 What experience do you have in programming ?	4	77923.00	19480.8	33.4222
Error	470	273948.24	582.9	
C. Total	474	351871.25		

Table D.1.40 Measure of fit for PM% by programming experience for semester 1 2012

RSquare	0.221453
RSquare Adj	0.214827
Root Mean Square Error	24.14267
Mean of Response	47.45377
Observations (or Sum Wgts)	475

Semester 2 1012

Table D.1.41 Analysis of variance for PM% by programming experience for semester 2 2012

Source	DF	Sum of Squares	Mean Square	F Ratio
Q10 What experience do you have in programming ?	4	60113.37	15028.3	33.9810
Error	517	228646.90	442.3	
C. Total	521	288760.27		

Table D.1.42 Measure of fit for PM% PM% by programming experience for semester 2 2012

RSquare	0.208177
RSquare Adj	0.202051
Root Mean Square Error	21.02991
Mean of Response	42.13389
Observations (or Sum Wgts)	522

D.2 Second implementation cycle 2012 of the Drawing Variable Diagrams Tutorial

D.2.1. Final marks for 2013 examinations (section 7.2.1)

Table D.2.1 Quantiles for final marks for respondents for both semesters 2013

		Semester 1	Semester 2
100.0%	maximum	93	94.09
99.5%		93	94.09
97.5%		90.975	92.2625
90.0%		80	89.034
75.0%	quartile	74	75
50.0%	median	60	57.53
25.0%	quartile	50	30.915
10.0%		40	18.708
2.5%		33	12.795
0.5%		33	9.14
0.0%	minimum	33	9.14

Table D.2.2 Summary statistics for final marks for respondents for both semesters 2013

	Semester 1	Semester 2
Mean	61.151515	54.721233
Std Dev	15.328448	24.71571
Std Err Mean	1.8868015	2.8927551
Upper 95% Mean	64.919718	60.487835
Lower 95% Mean	57.383312	48.954631
N	66	73
Skewness	-0.01156	-0.102583
Kurtosis	-0.777914	-1.179244

D.2.2 Biographical detail and descriptive statistics (section 7.3.3)

Table D.2.3 Biographical data of students in both semesters of 2013

	Semester 1 2013		Semester 2 2013	
Q1 Gender?			**N**	**% of Total**
1. Male	35	64.81%	47	72.31%
2. Female	19	35.19%	18	27.69%
All	54	100.00%	65	100.00%
Q2 What is your age?				
1. 19 - 22	20	37.04%	15	23.08%
2. 23 - 27	17	31.48%	21	32.31%
3. 28 - 32	9	16.67%	16	24.62%
4. 32 – 40	7	12.96%	10	15.38%
5. 41 +	1	1.85%	3	4.62%
All	54	100.00%	65	100.00%
Q3 Which ONE of the following describes your situation best?				
1. I am a full-time student who does not work at all.	13	24.07%	8	12.50%
2. I am a full-time student who works part-time for extra pocket money (not to pay for my studies).	2	3.70%	3	4.69%
3. I am a full-time student who works part-time to pay for my studies.	1	1.85%	5	7.81%
4. I work full-time and study after hours, and the work that I do is not related to my degree at all.	15	27.78%	17	26.56%
5. I work full-time and study after hours, and the work that I do is related to my degree	23	42.59%	29	45.31%
6. Other	0	0.00%	2	3.13%
All	54	100.00%	64	100.00%
Q4 My highest qualification is				
1. Matric	31	58.49%	41	64.06%
2. National certificate	7	13.21%	10	15.63%
3. Diploma	9	16.98%	10	15.63%
4. Degree	2	3.77%	2	3.13%
5. Post-graduate degree	4	7.55%	1	1.56%
All	53	100.00%	64	100.00%

Q5 My first language is				
1. English	25	47.17%	28	43.08%
2. Afrikaans	17	32.08%	19	29.23%
3. Other	11	20.75%	18	27.69%
All	53	100.00%	65	100.00%
Q6 If you do not have a South-African matric please choose the option you think are the most relevant to you. In my matric results				
1. I passed Mathematics (higher grade) or equivalent with a C-symbol or higher.	18	43.90%	26	52.00%
2. I passed Mathematics (higher grade) or equivalent with a D-symbol or lower.	8	19.51%	5	10.00%
3. I passed Mathematics (standard grade) or equivalent with a C-symbol or higher.	8	19.51%	13	26.00%
4. I passed Mathematics (standard grade) or equivalent with a D-symbol or lower.	7	17.07%	5	10.00%
5. I did not take Mathematics for matric.	0	0.00%	1	2.00%
All	41	100.00%	50	100.00%
Q7 If you do not have a South-African matric please choose the option you think are the most relevant to you. In my matric results				
1. I passed English (higher grade) or equivalent with a C-symbol or higher.	19	46.34%	29	58.00%
2. I passed English (higher grade) or equivalent with a D-symbol or lower.	15	36.59%	12	24.00%
3. I passed English (standard grade) or equivalent with a C-symbol or higher.	5	12.20%	6	12.00%
4. I passed English (standard grade) or equivalent with a D-symbol or lower.	2	4.88%	3	6.00%
5. I did not take English for matric.	0	0.00%	0	0.00%
All	41	100.00%	50	100.00%
Q8 Did you have Computer Applications Technology, Information Technology or Computer Studies at school?				
1 Yes	23	42.59%	34	52.31%
2 No	31	57.41%	31	47.69%
All	54	100.00%	65	100.00%
Q9 Please choose the option below that best describes your computer literacy level. If more than one option applies to you, choose the option that reflects your most recent computer literacy enrichment experience.				
1. None	0	0.00%	0	0.00%
2. Self-taught	17	31.48%	13	20.00%
3. Did Computer Applications Technology, Information Technology or Computer Studies at school	8	14.81%	10	15.38%
4. Passed or enrolled for ICDL or EUP at Unisa	4	7.41%	12	18.46%
5. Done any other computer literacy course	8	14.81%	7	10.77%
6. Use a computer daily at work	15	27.78%	19	29.23%
7. Other means of exposure/experience towards computer literacy development	2	3.70%	4	6.15%
All	54	100.00%	65	100.00%

D.2.3 English and Mathematics marks (section 7.3.4.1)

Table D.2.4 Quantiles for Mathematics marks for respondents for both semesters 2013

		Semester 1	Semester 2
100.0%	maximum	93	89
99.5%		93	89
97.5%		90.975	85.3
90.0%		80	80
75.0%	quartile	74	74
50.0%	median	60	60
25.0%	quartile	50	50
10.0%		40	40
2.5%		33	39.475
0.5%		33	33
0.0%	minimum	33	33

Table D.2.5 Summary statistics for Mathematics marks for respondents for both semesters 2013

	Semester 1	Semester 2
Mean	61.151515	61.723684
Std Dev	15.328448	14.743675
Std Err Mean	1.8868015	1.6912156
Upper 95% Mean	64.919718	65.092758
Lower 95% Mean	57.383312	58.35461
N	66	76
Skewness	-0.01156	-0.103925
Kurtosis	-0.777914	-1.153955

Table D.2.6 Quantiles for English marks for respondents for both semesters 2013

		Semester 1	Semester 2
100.0%	maximum	82	88
99.5%		82	88
97.5%		80.65	87.075
90.0%		78.3	80
75.0%	quartile	70	70
50.0%	median	60	60
25.0%	quartile	50	50
10.0%		41.4	50
2.5%		37.725	40
0.5%		33	40
0.0%	minimum	33	40

Table D.2.7 Summary statistics for English marks for respondents for both semesters 2013

	Semester 1	Semester 2
Mean	59.530303	62.223684
Std Dev	12.098595	11.89913
Std Err Mean	1.489234	1.3649238
Upper 95% Mean	62.504509	64.942752
Lower 95% Mean	56.556097	59.504616
N	66	76
Skewness	-0.021532	0.105484
Kurtosis	-0.784655	-0.574522

D.2.4 Learning experience (questions 18, 19, 23 to 36, 42 and 43) (section 7.3.4.5).

Table D.2.8 Quantiles for learning experience for 2013 respondents for both semesters

		Semester 1	Semester 2
100.0%	maximum	5	5
99.5%		5	5
97.5%		4.975	5
90.0%		4.789	4.694
75.0%	quartile	4.139	3.917
50.0%	median	3.667	3.194
25.0%	quartile	3	2.694
10.0%		2.222	1.444
2.5%		1.403	1.078
0.5%		1.278	1
0.0%	minimum	1.278	1

Table D.2.9 Summary statistics for learning experience for 2013 respondents for both semesters

	Semester 1	Semester 2
Mean	3.5431573	3.2239839
Std Dev	0.907682	1.0004984
Std Err Mean	0.1202254	0.1250623
Upper 95% Mean	3.7839978	3.4739009
Lower 95% Mean	3.3023169	2.9740668
N	57	64
Skewness	-0.461695	-0.258729
Kurtosis	-0.167435	-0.104652

Table D.2.10 Cronbach's coefficient alpha for learning experience semester 1 2013

Excluded Col	**α**
Q18 Do you feel that using variable diagrams improves your programming skills?	0.9645
Q19 Do you feel that using variable diagrams assist with understanding the flow of logic in a program?	0.9653
Q23 Did watching the Drawing Variable Diagrams tutorial, help you to understand if statements?	0.9602
Q24 Did watching the Drawing Variable Diagrams tutorial, help you to understand while loops?	0.9600
Q25 Did watching the Drawing Variable Diagrams tutorial, help you to understand nested if statements?	0.9597
Q26 Did watching the Drawing Variable Diagrams tutorial, help you to understand switch statements?	0.9605
Q27 Did watching the Drawing Variable Diagrams tutorial, help you to understand the difference between while loops and do É while loops?	0.9606
Q28 Did watching the Drawing Variable Diagrams tutorial, help you to understand what happens when a function is executed?	0.9602
Q29 Did watching the Drawing Variable Diagrams tutorial, help you to understand value parameters?	0.9603
Q30 Did watching the Drawing Variable Diagrams tutorial, help you to understand reference parameters?	0.9606
Q31 Did watching the Drawing Variable Diagrams tutorial, help you to understand the difference between value and reference parameters?	0.9614
Q32 Did watching the Drawing Variable Diagrams tutorial, help you to understand one-dimensional arrays?	0.9610
Q33 Did watching the Drawing Variable Diagrams tutorial, help you to understand two-dimensional arrays?	0.9610
Q34 Did watching the Drawing Variable Diagrams tutorial, help you to understand strings?	0.9626
Q35 Did watching the Drawing Variable Diagrams tutorial, help you to understand structs?	0.9618
Q36 To trace a program means to form a mental picture of what the program does and how it is done. To what degree did the Drawing Variable Diagrams tutorial assist you to master tracing?	0.9632
Q42 Did you find that the Drawing Variable Diagrams tutorial is directly applicable to the programming assignments in the course?	0.9637
Q43 Do you think that you will apply the general concept of variable diagrams in future programming projects?	0.9674
Entire set	**0.9640**

Table D.2.11 Cronbach's coefficient alpha for learning experience semester 2 2013

Excluded Col	**α**
Q18 Do you feel that using variable diagrams improves your programming skills?	0.9670
Q19 Do you feel that using variable diagrams assist with understanding the flow of logic in a program?	0.9682
Q23 Did watching drawing variable diagram tutorial helps you understand if statements	0.9659
Q24 Did watching the Drawing Variable Diagrams tutorial, help you to understand if statements?	0.9649
Q25 Did watching the Drawing Variable Diagrams tutorial, help you to understand nested if statements?	0.9646
Q26 Did watching the Drawing Variable Diagrams tutorial, help you to understand switch statements?	0.9649
Q27 Did watching the Drawing Variable Diagrams tutorial, help you to understand the difference between while loops and do É while loops?	0.9649
Q28 Did watching the Drawing Variable Diagrams tutorial, help you to understand what happens when a function is executed?	0.9653
Q29 Did watching the Drawing Variable Diagrams tutorial, help you to understand value parameters?	0.9655
Q30 Did watching the Drawing Variable Diagrams tutorial, help you to understand reference parameters?	0.9653
Q31 Did watching the Drawing Variable Diagrams tutorial, help you to understand the difference between value and reference parameters?	0.9650
Q32 Did watching the Drawing Variable Diagrams tutorial, help you to understand one-dimensional arrays?	0.9647
Q33 Did watching the Drawing Variable Diagrams tutorial, help you to understand two-dimensional arrays?	0.9652
Q34 Did watching the Drawing Variable Diagrams tutorial, help you to understand strings?	0.9665
Q35 Did watching the Drawing Variable Diagrams tutorial, help you to understand structs?	0.9660
Q36 To trace a program means to form a mental picture of what the program does and how it is done. To what degree did the Drawing Variable Diagrams tutorial assist you to master tracing?	0.9679
Q42 Did you find that the Drawing Variable Diagrams tutorial is directly applicable to the programming assignments in the course?	0.9687
Q43 Do you think that you will apply the general concept of variable diagrams in future programming projects?	0.9680
Entire set	**0.9679**

D.2.5 Positive user experience (questions 37 to 41) (section 7.3.4.6).

Table D.2.12 Quantiles for Positive user experience for all respondents for both semesters 2013

		Semester 1	**Semester 2**
100.0%	maximum	5	5
99.5%		5	5
97.5%		5	5
90.0%		4.8	4.58
75.0%	quartile	4.2	4
50.0%	median	3.8	3.3
25.0%	quartile	3	2.6
10.0%		2.08	2
2.5%		1.085	1.21
0.5%		1	1
0.0%	minimum	1	1

Table D.2.13 Summary statistics for Positive user experience for all respondents for both semesters 2013

	Semester 1	**Semester 2**
Mean	3.5696429	3.2608333
Std Dev	1.0190762	0.9557184
Std Err Mean	0.1361798	0.1233827
Upper 95% Mean	3.8425532	3.5077216
Lower 95% Mean	3.2967325	3.0139451
N	56	60
Skewness	-0.731662	-0.104789
Kurtosis	0.0616672	-0.593283

Table D.2.14 Cronbach’s coefficient alpha for positive user experience in semester 1 2013

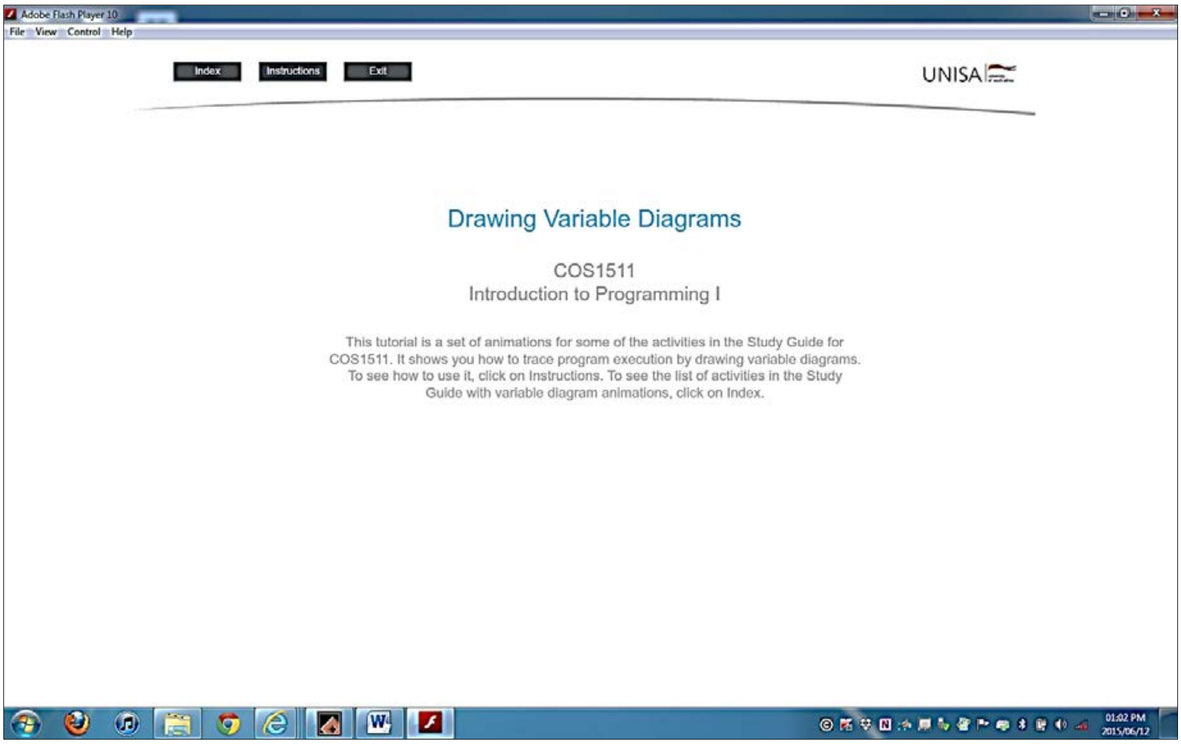
Excluded Col	**α**
Q37 Did you find it interesting to use the Drawing Variable Diagrams tutorial?	0.7851
Q38 Did you find it motivating to use the Drawing Variable Diagrams tutorial?	0.7933
Q39 Did you enjoy using the Drawing Variable Diagrams tutorial?	0.7851
Q40 Did you find it frustrating to use the Drawing Variable Diagrams tutorial? 2	0.8987
Q41 Did you find the Drawing Variable Diagrams tutorial easy to use?	0.8391
Entire set	**0.8542**

Table D.2.15 Cronbach’s coefficient alpha for positive user experience in semester 2 2013

Excluded Col	**α**
Q37 Did you find it interesting to use the Drawing Variable Diagrams tutorial?	0.7504
Q38 Did you find it motivating to use the Drawing Variable Diagrams tutorial?	0.7345
Q39 Did you enjoy using the Drawing Variable Diagrams tutorial?	0.7293
Q40 Did you find it frustrating to use the Drawing Variable Diagrams tutorial? 2	0.8713
Q41 Did you find the Drawing Variable Diagrams tutorial easy to use?	0.8254
Entire set	**0.8229**

Appendix E Instructions for using the Drawing Variable Diagrams Tutorial

E.1 Landing page and instructions for first version of the Drawing Variable Diagrams Tutorial

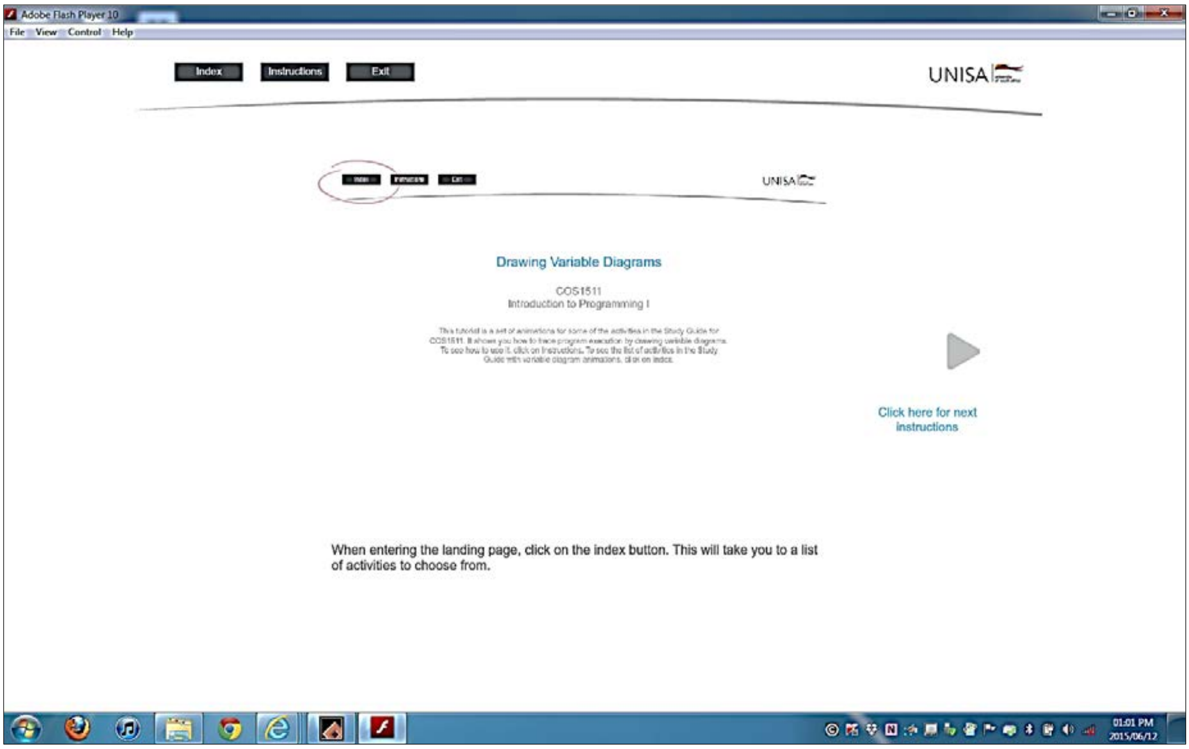


Drawing Variable Diagrams

COS1511
Introduction to Programming I

This tutorial is a set of animations for some of the activities in the Study Guide for COS1511. It shows you how to trace program execution by drawing variable diagrams. To see how to use it, click on Instructions. To see the list of activities in the Study Guide with variable diagram animations, click on Index.

Figure E.2 Landing page of tutorial



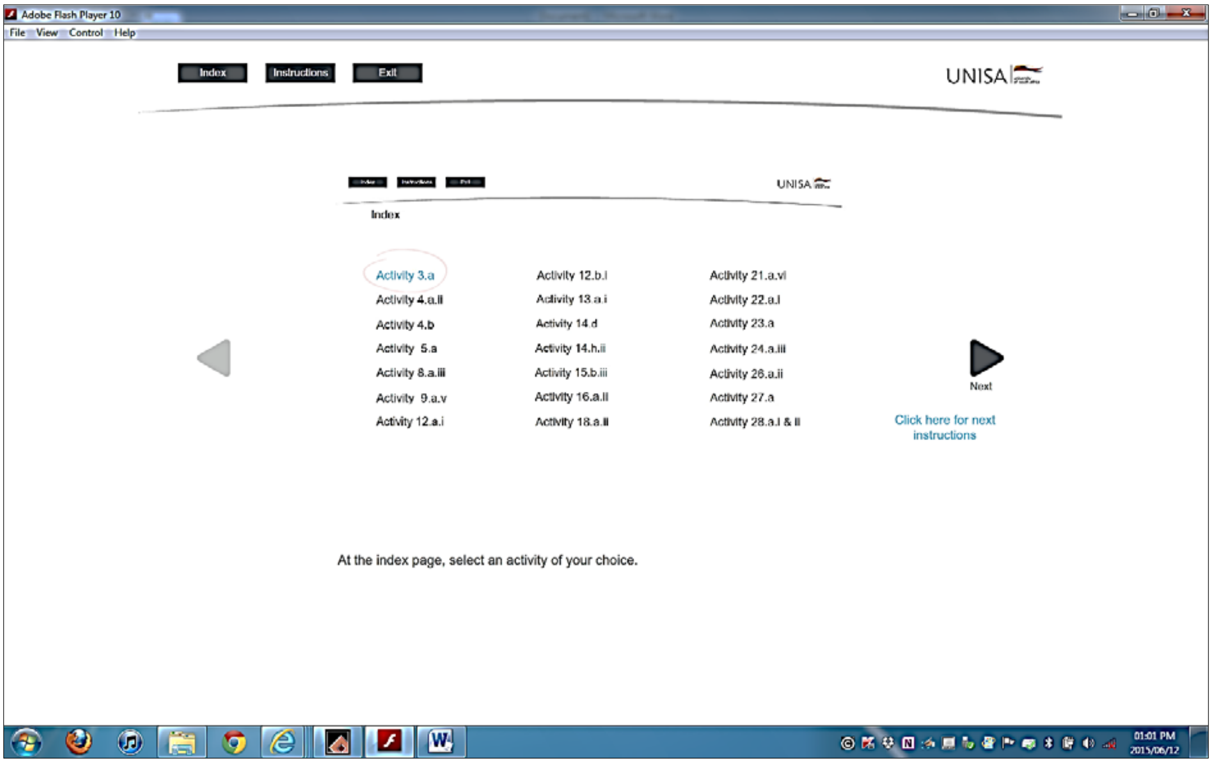
Drawing Variable Diagrams

COS1511
Introduction to Programming I

This tutorial is a set of animations for some of the activities in the Study Guide for COS1511. It shows you how to trace program execution by drawing variable diagrams. To see how to use it, click on Instructions. To see the list of activities in the Study Guide with variable diagram animations, click on index.

When entering the landing page, click on the index button. This will take you to a list of activities to choose from.

Figure E.3 First page of instructions

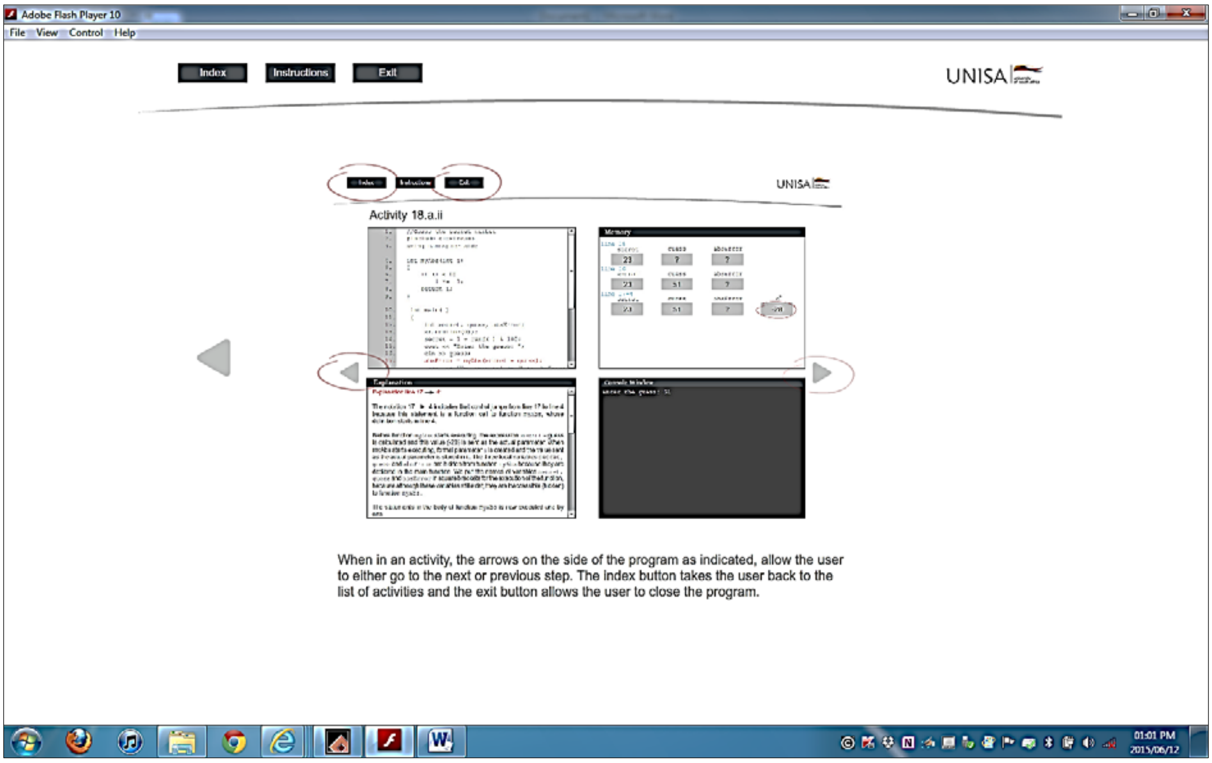


Index

Activity 3.a
Activity 4.a.ii
Activity 4.b
Activity 5.a
Activity 8.a.iii
Activity 9.a.v
Activity 12.a.i
Activity 12.b.i
Activity 13.a.i
Activity 14.d
Activity 14.h.ii
Activity 15.b.iii
Activity 16.a.ii
Activity 18.a.ii
Activity 21.a.vi
Activity 22.a.i
Activity 23.a
Activity 24.a.iii
Activity 26.a.ii
Activity 27.a
Activity 28.a.i & ii

At the index page, select an activity of your choice.

Figure E.4 Second page of instructions



Activity 18.a.ii

When in an activity, the arrows on the side of the program as indicated, allow the user to either go to the next or previous step. The index button takes the user back to the list of activities and the exit button allows the user to close the program.

Figure E.5 Third page of instructions

E.2 Instructions for second version of the Tutorial to Draw Variable Diagrams

Instructions for using the Drawing Variable Diagrams tutorial

Welcome to the Drawing Variable Diagrams tutorial and its instructions.

This is a PowerPoint presentation.

To view each new page, you have to press Enter.

This set of instructions cover the following topics:

1. Introduction
2. What is a variable?
3. What is a variable diagram?
4. The purpose of variable diagrams
5. The purpose of the Drawing Variable Diagrams tutorial
6. Activities in the Drawing Variable Diagrams tutorial
7. How to use the Drawing Variable Diagrams tutorial
8. The Landing Page
9. The Index page
10. Explanation of an activity screen
11. The Program code box
12. The Memory box
13. The Explanation box
14. The Console window box
15. The relationship between the four boxes on the screen for an activity
16. How to follow how variable diagrams are drawn
17. Notes
18. At the end of an activity
19. Using the Drawing Variable Diagrams tutorial to see how variable diagrams are drawn for activity 3.a.i

1. Introduction

- The Drawing Variable Diagrams tutorial shows you how to draw variable diagrams for various programming constructs which you learn in COS1511.
- You should use it together with your COS1511 Study Guide.

- In the COS1511 Study Guide we use variable diagrams to illustrate how the values of variables change as a program is executed.

- In the Study Guide, this tutor icon indicates that there is an activity in the Drawing Variable Diagrams Tutorial that animates the variable diagrams for the corresponding activity in the Study Guide.

- You should then use the tutorial to watch the effect of the program statements on the variables in the appropriate activity or subactivity.

To understand what a variable diagram is, you need to understand what is a variable.

2. What is a variable?

- A variable is a space or **memory position** in the computer's memory that has been set aside to store a value in a program.

- The **value** of a variable can change or vary, which is why we call it a variable.

- A variable has a **name** associated with it to identify it, as well as a data type.

- The **data type** specifies what kind of values may be stored in the memory position.

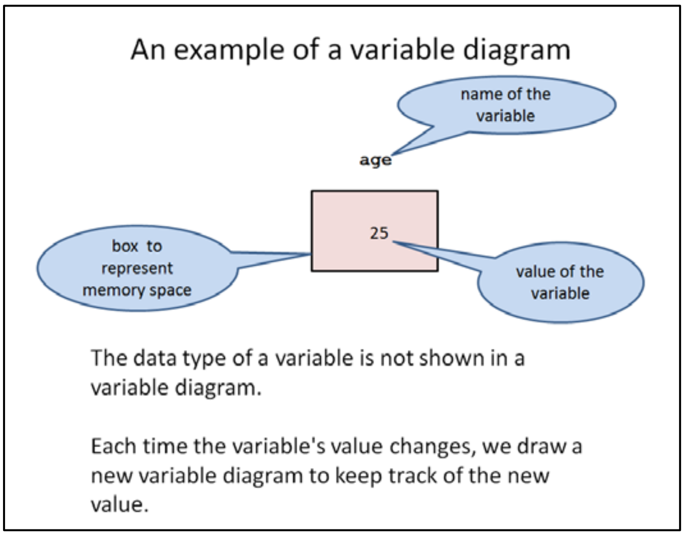
- So we can say that each variable in a program has a name, a data type, a value and a space in memory where its value can be stored.

3. What is a variable diagram?

- A variable diagram is a graphical representation of the space or memory position associated with a variable at a specific moment during the program execution.

- We use variable diagrams to keep track of the values of the variables inside the computer's memory.

- When we draw a variable diagram for a variable, we draw a box to represent the memory space and write the name of the variable above it. We write the value of the variable inside the box.


An example of a variable diagram

The data type of a variable is not shown in a variable diagram.

Each time the variable's value changes, we draw a new variable diagram to keep track of the new value.

4. The purpose of variable diagrams

- We draw variable diagrams to trace a program, that is, to form a mental picture of what the program does and how it is done.
- This helps us to understand algorithms and also to debug programs.
- An algorithm is a set of instructions to perform a task, for example to sort a list of names in alphabetic order.
- To debug a program means to find an error in a program where the error causes the program to do something else than what we intend the program to do.

5. The purpose of the Drawing Variable Diagrams tutorial

- The Drawing Variable Diagrams Tutorial shows one example of how to draw variable diagrams for each new programming construct you learn in the COS1511 Study Guide.
- If you know how to draw variable diagrams, you can draw your own variable diagrams on paper for any program to understand what it does, or to debug it.
- So the purpose of the Drawing Variable Diagrams Tutorial is to show you how to draw variable diagrams so that you eventually can draw your own variable diagrams to figure out any program.

6. Activities in the Drawing Variable Diagrams tutorial

- Activity 3.a.i is the first activity in the Study Guide that the Drawing Variable Diagrams Tutorial demonstrates.
- We did not provide animated variable diagrams for all the activities in the Study Guide, but only for those activities where you learn about a new programming construct.
- This is to help you understand what the effect of the new programming construct you are learning, is, and how to draw variable diagrams for this construct.

7. How to use the Drawing Variable Diagrams tutorial

- This tutorial should be used together with your COS1511 Study Guide.
- Once you have studied a section in the COS1511 Study Guide that shows the tutor icon 🎓 you can watch an animation for the corresponding activity in the Drawing Variable Diagrams tutorial to help you understand how the variable diagrams are drawn.

8. The Landing page

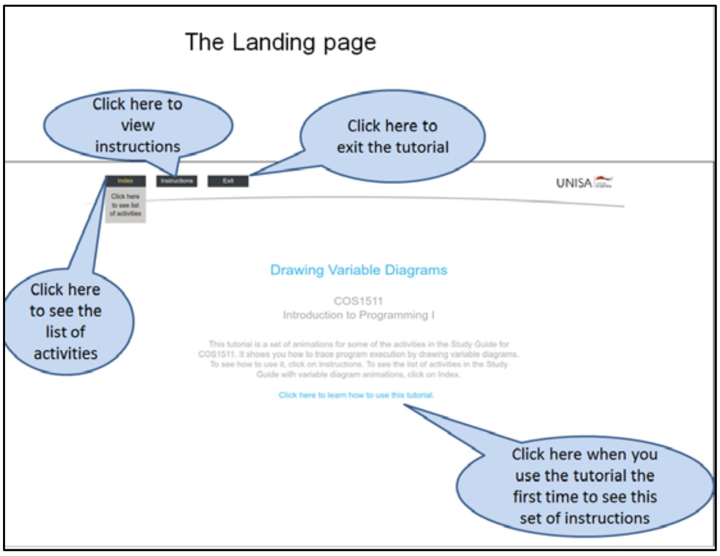
The first page you see when you enter the Drawing Variable Diagrams Tutorial, is called the landing page.

This page has three menu buttons on top: Index, Instructions and Exit.

Click on the Index button to go to the Index page to see the list of activities that the tutorial animates.

Click on the Instructions button to see this set of instructions.

Click on the Exit button to leave the Drawing Variable Diagrams Tutorial.



The Landing page

Click here to view instructions

Click here to exit the tutorial

Click here to see the list of activities

Drawing Variable Diagrams

COS1511
Introduction to Programming I

This tutorial is a set of animations for some of the activities in the Study Guide for COS1511. It shows you how to trace program execution by drawing variable diagrams. To see how to use it, click on Instructions. To see the list of activities in the Study Guide with variable diagram animations, click on Index.

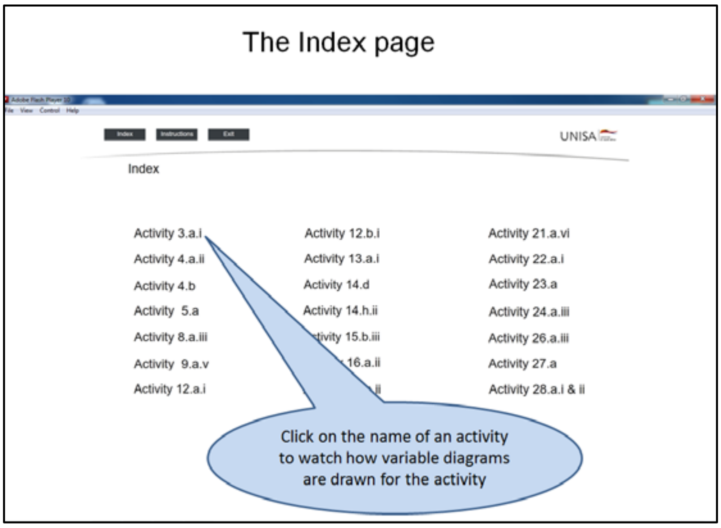
Click here to learn how to use this tutorial.

Click here when you use the tutorial the first time to see this set of instructions

9. The Index page

The Index page shows a list of all the activities in the Study for which the variable diagrams have been animated.

Click on the name of an activity to watch how variable diagrams are drawn for the activity.



The Index page

Index

Activity 3.a.i
Activity 4.a.ii
Activity 4.b
Activity 5.a
Activity 8.a.iii
Activity 9.a.v
Activity 12.a.i

Activity 12.b.i
Activity 13.a.i
Activity 14.d
Activity 14.h.ii
tivity 15.b.iii
16.a.ii
ii

Activity 21.a.vi
Activity 22.a.i
Activity 23.a
Activity 24.a.iii
Activity 26.a.iii
Activity 27.a
Activity 28.a.i & ii

Click on the name of an activity to watch how variable diagrams are drawn for the activity

10. Explanation of an activity screen

We will use Activity 3.a.i to demonstrate what you have to do when watching an activity to benefit from it. In an activity, four boxes are shown on the screen:

the Program code box
the Memory box
the Explanation box and
the Console Window

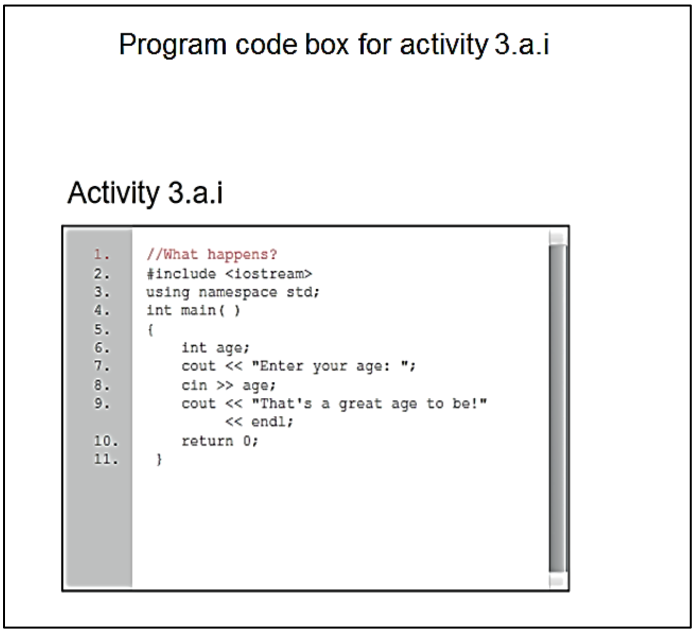
11. Program code box

The top left box contains the program code of the program for which variable diagrams are drawn.

You should first study the program code to try to get an idea of what the program does.

When a statement in the program code box is being ‘executed’, it is highlighted in red.

Statements are highlighted in the order that they are executed when the program is run.



Program code box for activity 3.a.i

Activity 3.a.i

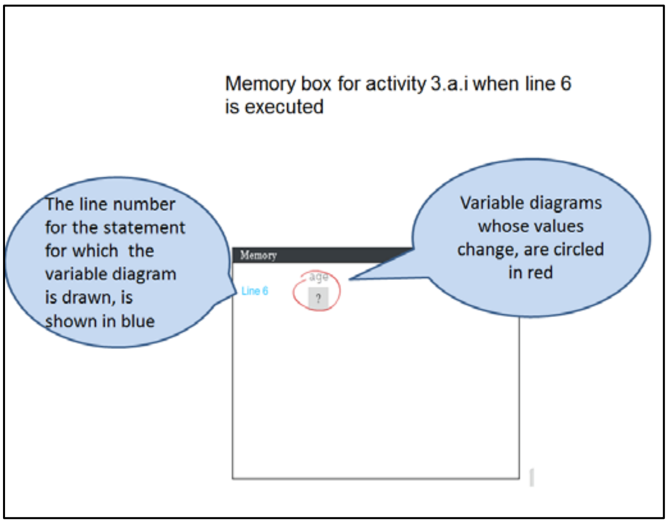
```
1.   //What happens?
2.   #include <iostream>
3.   using namespace std;
4.   int main( )
5.   {
6.       int age;
7.       cout << "Enter your age: ";
8.       cin >> age;
9.       cout << "That's a great age to be!"
              << endl;
10.      return 0;
11.   }
```

12. Memory box

The top right box represents the computer memory.

This is where we show the variable diagrams.

All the variable diagrams for the program variables up to the highlighted statement (being ‘executed’) are shown. This allows you to follow or track how their values have changed during program execution.



Memory box for activity 3.a.i when line 6 is executed

The line number for the statement for which the variable diagram is drawn, is shown in blue

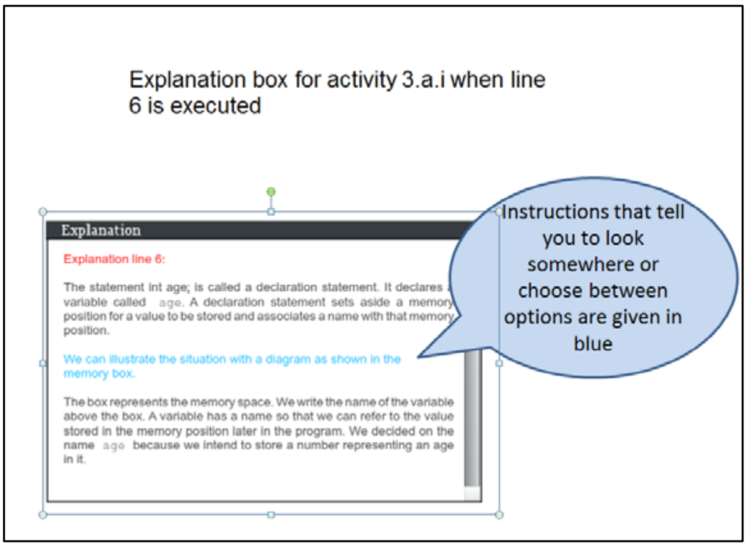
Variable diagrams whose values change, are circled in red

13. Explanation box

The bottom left box provides an explanation for the highlighted program statement in the program code box.

Sometimes it will contain additional information, or allow you to choose between two options.

When you have to choose between two options, you have to click on the option that you choose before the animation will continue.



Explanation box for activity 3.a.i when line 6 is executed

Explanation

Explanation line 6:

The statement int age; is called a declaration statement. It declares a variable called age. A declaration statement sets aside a memory position for a value to be stored and associates a name with that memory position.

We can illustrate the situation with a diagram as shown in the memory box.

The box represents the memory space. We write the name of the variable above the box. A variable has a name so that we can refer to the value stored in the memory position later in the program. We decided on the name age because we intend to store a number representing an age in it.

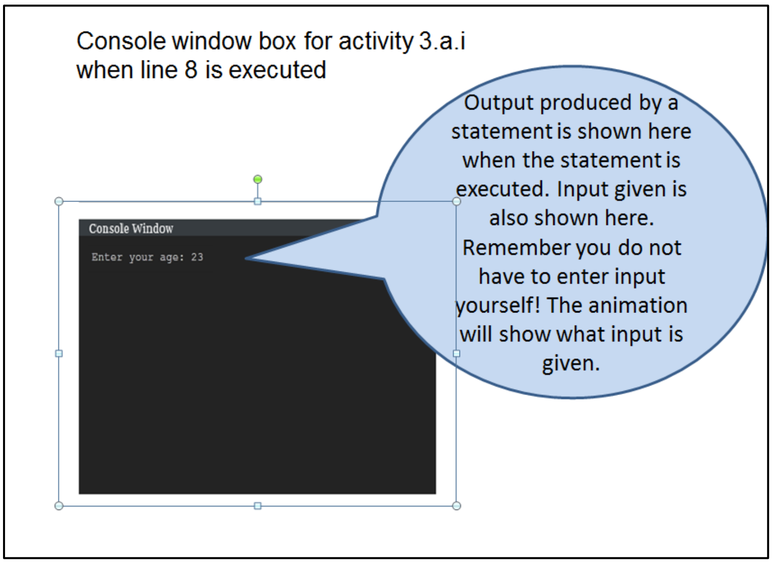
Instructions that tell you to look somewhere or choose between options are given in blue

14. Console Window box

The bottom right box (Console window) shows the output that the program produces.

When an output statement is ‘executed’, its output is displayed in the Console window, in the same way that it will be displayed in the MingW compiler you use to compile your programs with.

It will also show the input we pretend to give the program as it ‘executes’.



Console window box for activity 3.a.i when line 8 is executed

Console Window

```
Enter your age: 23
```

Output produced by a statement is shown here when the statement is executed. Input given is also shown here. Remember you do not have to enter input yourself! The animation will show what input is given.

15. The relationship between the four boxes on the screen for an activity

The statements in the program code box are highlighted in the order that the program is executed.

When a statement is highlighted, an explanation for the highlighted statement is given in the Explanation box.

At the same time the Memory box shows how the variable diagram for the statement is drawn, if the statement requires it.

Simultaneously the Console window shows the output the statement produces (if any) and if input is given, what is entered.

16. How to follow how variable diagrams are drawn

First study the program code to try to get an idea of what the program does.

Then read the highlighted program statement.

Next, read the explanation for the statement to make sure you understand what the highlighted statement does.

Then check the Memory box to see how the variable diagram for this statement is drawn, and how the computer memory changed.

Also look at the Console window to see what (if any) output the statement produces, or what input is given for the statement.

Make sure you understand what a program statement does, and what its effect is on the variables involved, as well as what output it produces (if any).

Once you understand the effect of a statement and how a variable diagram for the statement is drawn, click on the Next button on the right-hand side of the screen to see what happens when the next statement is executed.

You can also use the Back button on the left-hand side of the screen to go back to the previous statement in the program.

17. Notes:

You need not provide any input when a statement requires input. The animation will show some input and what the effect thereof is.

Sometimes you may have to choose between two options to see different results for different inputs, or to answer a question to help you make sure you understand the program statement.

Blue instructions in the Explanation box tell you to look somewhere or to choose between two options.

We do not draw variable diagrams for all statements that is executed, but only when the statement changes the computer memory.

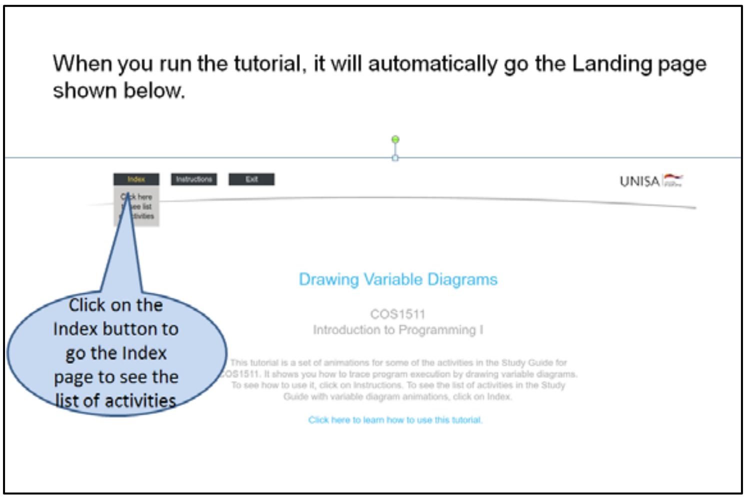
18. At the end of an activity

When the last statement in the program has been ‘executed’, you can click the Index button to go back to the Index page if you want to watch another activity, or the Exit button if you want to exit the tutorial.

19. Using the Drawing Variable Diagrams tutorial to see how variable diagrams are drawn for activity 3.a.i

We use numbered call-outs to show how someone would watch activity 3.a.i to see how variable diagrams are drawn for this activity.

In this process we will guide you where and what to look at to make sure you understand how to use the tutorial to learn how to draw variable diagrams for the programming constructs you learn in COS1511.



When you run the tutorial, it will automatically go the Landing page shown below.

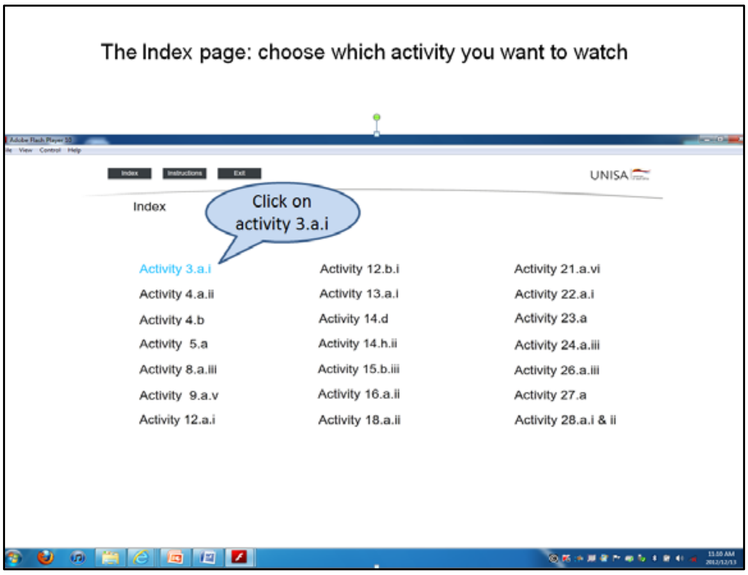
Click on the Index button to go the Index page to see the list of activities

Drawing Variable Diagrams

COS1511
Introduction to Programming I

This tutorial is a set of animations for some of the activities in the Study Guide for COS1511. It shows you how to trace program execution by drawing variable diagrams. To see how to use it, click on Instructions. To see the list of activities in the Study Guide with variable diagram animations, click on Index.

Click here to learn how to use this tutorial.



The Index page: choose which activity you want to watch

Click on activity 3.a.i

Index

Activity 3.a.i
Activity 4.a.ii
Activity 4.b
Activity 5.a
Activity 8.a.iii
Activity 9.a.v
Activity 12.a.i
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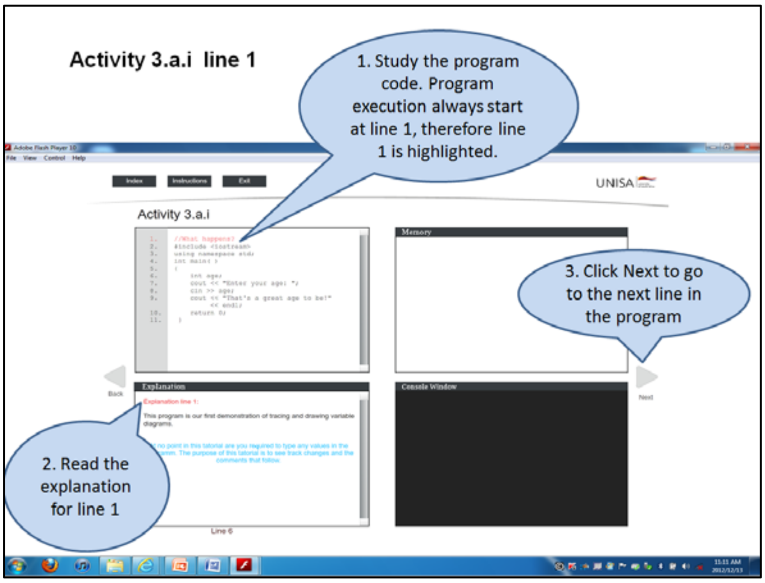
Activity 18.a.ii
Activity 21.a.vi
Activity 22.a.i
Activity 23.a
Activity 24.a.iii
Activity 26.a.iii
Activity 27.a
Activity 28.a.i & ii



Activity 3.a.i line 1

1. Study the program code. Program execution always start at line 1, therefore line 1 is highlighted.

2. Read the explanation for line 1

3. Click Next to go to the next line in the program

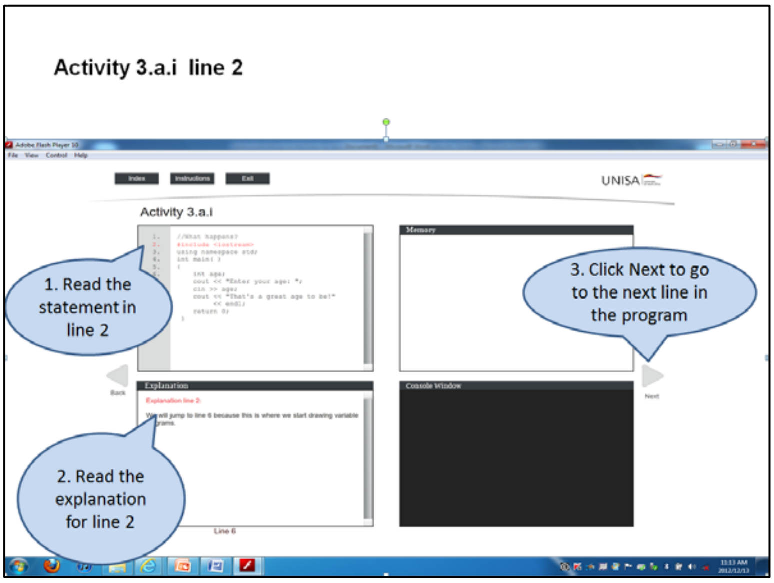
```
1.  //What happens?
2.  #include <iostream>
3.  using namespace std;
4.  int main( )
5.  {
6.       int age;
7.       cout << "Enter your age: ";
8.       cin >> age;
9.       cout << "That's a great age to be!"
             << endl;
10.      return 0;
11.  }
```

Explanation

Explanation line 1:

This program is our first demonstration of tracing and drawing variable diagrams.

t no point in this tutorial are you required to type any values in the rogramm. The purpose of this tutorial is to see track changes and the comments that follow.



Activity 3.a.i line 2

1. Read the statement in line 2

2. Read the explanation for line 2

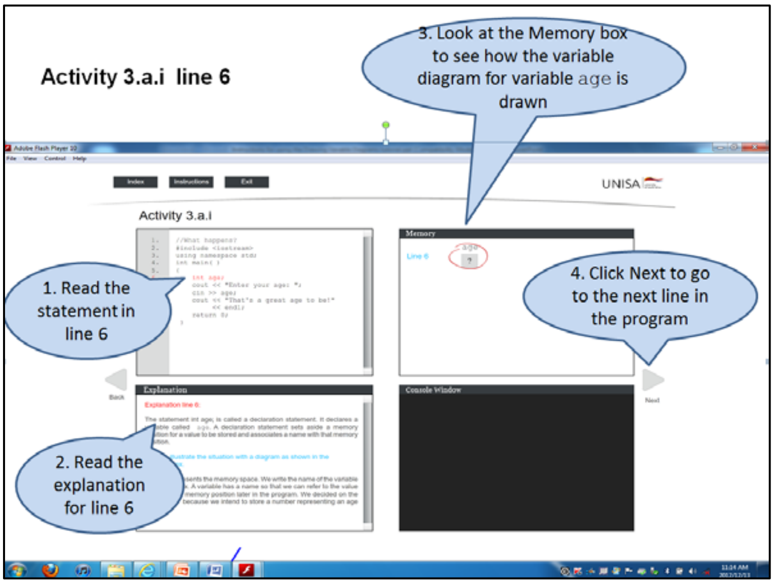
3. Click Next to go to the next line in the program

```
//What happens?
#include <iostream>
using namespace std;
int main( )
{
     int age;
     cout << "Enter your age: ";
     cin >> age;
     cout << "That's a great age to be!"
           << endl;
     return 0;
}
```

Explanation

Explanation line 2:

We will jump to line 6 because this is where we start drawing variable rams.



Activity 3.a.i line 6

1. Read the statement in line 6

2. Read the explanation for line 6

3. Look at the Memory box to see how the variable diagram for variable age is drawn

4. Click Next to go to the next line in the program

```
//What happens?
#include <iostream>
using namespace std;
int main( )
{
     int age;
     cout << "Enter your age: ";
     cin >> age;
     cout << "That's a great age to be!"
           << endl;
     return 0;
}
```

Explanation

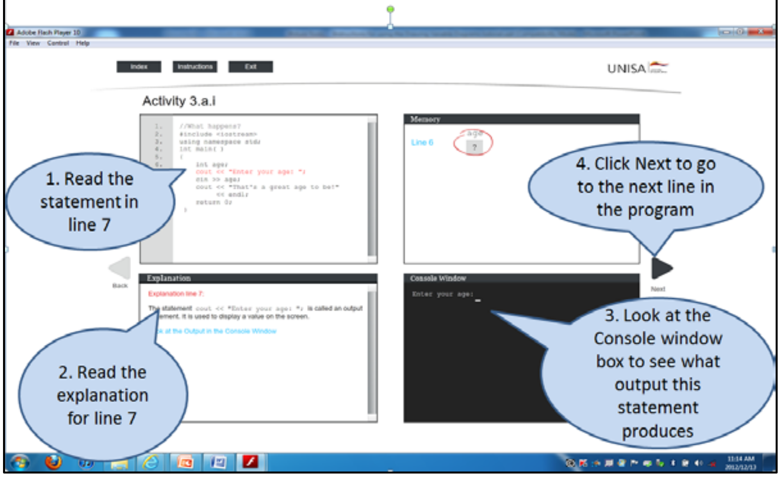
Explanation line 6:

The statement int age; is called a declaration statement. It declares a able called age. A declaration statement sets aside a memory ition for a value to be stored and associates a name with that memory ation.

llustrate the situation with a diagram as shown in the x.

esents the memory space. We write the name of the variable x. A variable has a name so that we can refer to the value memory position later in the program. We decided on the because we intend to store a number representing an age

Activity 3.a.i line 7



Activity 3.a.i

```
1.  //What happens?
2.  #include <iostream>
3.  using namespace std;
4.  int main( )
5.  {
6.      int age;
        cout << "Enter your age: ";
        cin >> age;
        cout << "That's a great age to be!"
             << endl;
        return 0;
    }
```

Memory

Line 6 age ?

Explanation

Explanation line 7:

The statement `cout << "Enter your age: ";` is called an output statement. It is used to display a value on the screen.

Look at the Output in the Console Window

Console Window

```
Enter your age: _
```

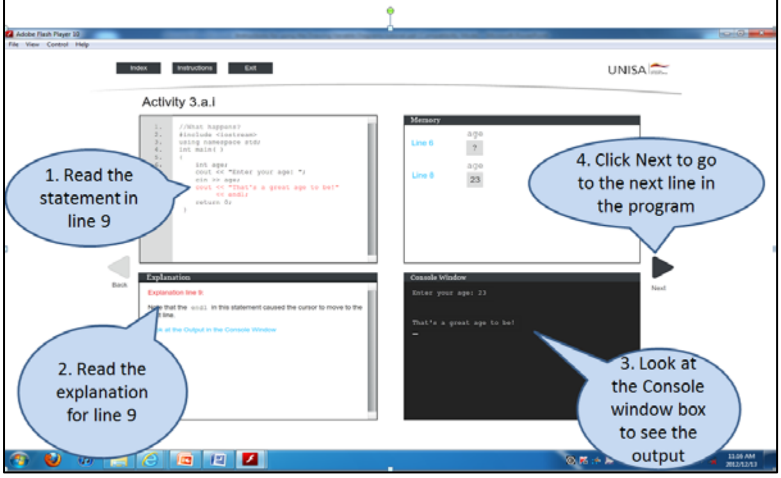
1. Read the statement in line 7

2. Read the explanation for line 7

3. Look at the Console window box to see what output this statement produces

4. Click Next to go to the next line in the program

Activity 3.a.i line 9



Activity 3.a.i

```
1.  //What happens?
2.  #include <iostream>
3.  using namespace std;
4.  int main( )
5.  {
6.      int age;
        cout << "Enter your age: ";
        cin >> age;
        cout << "That's a great age to be!"
             << endl;
        return 0;
    }
```

Memory

Line 6 age ?

Line 8 age 23

Explanation

Explanation line 9:

Note that the `endl` in this statement caused the cursor to move to the next line.

Look at the Output in the Console Window

Console Window

```
Enter your age: 23


That's a great age to be!
_
```

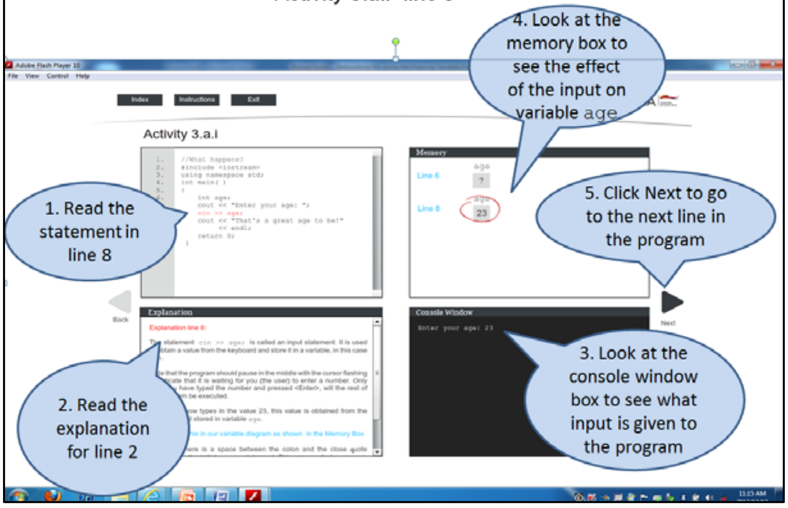
1. Read the statement in line 9

2. Read the explanation for line 9

3. Look at the Console window box to see the output

4. Click Next to go to the next line in the program

Activity 3.a.i line 8



Activity 3.a.i

```
1.  //What happens?
2.  #include <iostream>
3.  using namespace std;
4.  int main( )
5.  {
6.      int age;
        cout << "Enter your age: ";
        cin >> age;
        cout << "That's a great age to be!"
             << endl;
        return 0;
    }
```

Memory

Line 6 age ?

Line 8 age 23

Explanation

Explanation line 8:

The statement `cin >> age;` is called an input statement. It is used to obtain a value from the keyboard and store it in a variable, in this case

e that the program should pause in the middle with the cursor flashing icate that it is waiting for you (the user) to enter a number. Only have typed the number and pressed <Enter>, will the rest of be executed.

ow types in the value 23, this value is obtained from the stored in variable `age`.

his in our variable diagram as shown in the Memory Box

here is a space between the colon and the close quote

Console Window

```
Enter your age: 23
```

1. Read the statement in line 8

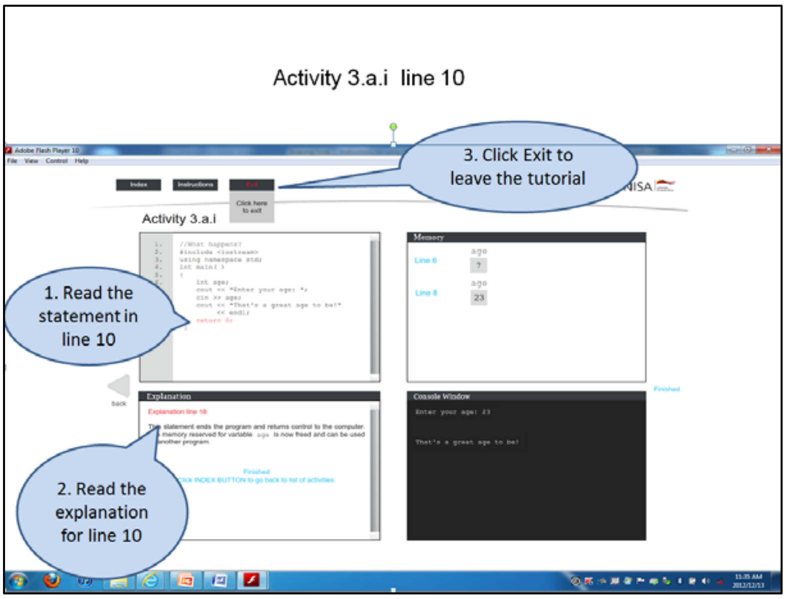
2. Read the explanation for line 2

3. Look at the console window box to see what input is given to the program

4. Look at the memory box to see the effect of the input on variable age

5. Click Next to go to the next line in the program

Activity 3.a.i line 10



```
//What happens?
#include <iostream>
using namespace std;
int main( )
{
    int age;
    cout << "Enter your age: ";
    cin >> age;
    cout << "That's a great age to be!"
        << endl;
    return 0;
}
```

Explanation line 10:

This statement ends the program and returns control to the computer. The memory reserved for variable age is now freed and can be used by another program.

Finished
Click INDEX BUTTON to go back to list of activities.

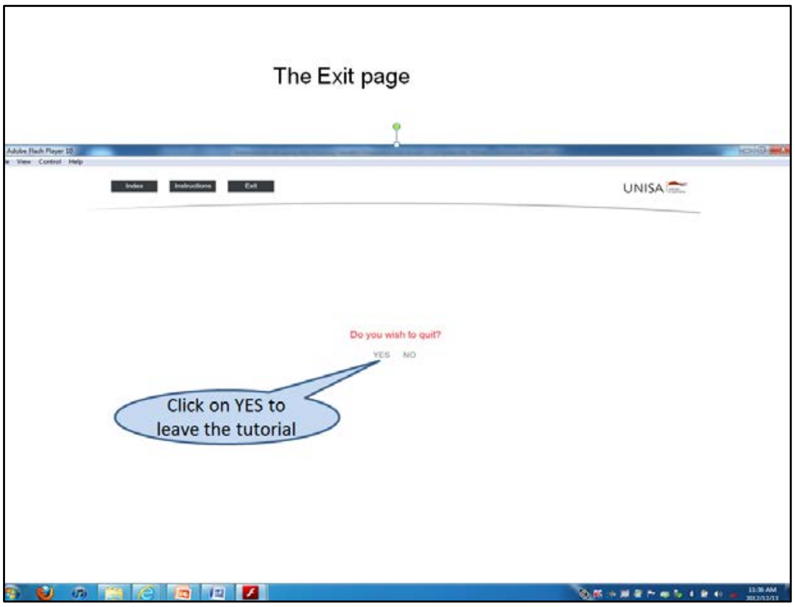
```
Enter your age: 23


That's a great age to be!
```

1. Read the statement in line 10

2. Read the explanation for line 10

3. Click Exit to leave the tutorial

The Exit page



Do you wish to quit?

YES NO

Click on YES to leave the tutorial

This is the end of this set of instructions.

Good luck with your studies!

Appendix F A framework of guidelines for developing and creating visualizations for teaching programming

Table F.1 A framework of guidelines for developing and creating visualizations for teaching programming, with references.

Guideline	References	Reason/explanation	Considerations/Comments
References from CER are blue, from educational psychology pink, from computer graphics purple, expansions / additional guidelines green.			
27. Actively engage learners with –		Meaningful learning requires *active processing*, that only occurs when the learner engages in cognitive processes such as extracting relevant material, organising it into a coherent representation and integrating it with prior knowledge (Mayer & Moreno, 2002). Prompting learners to engage in active processing of the learning material increase germane cognitive load, which encourages learning by facilitating the construction or automation of cognitive schemas (Wouters et al., 2008). Prompts to explore the different views and data sets provided, as well as periodic questions, not only engage learners, but can also motivate them (Hansen et al., 2002).	The degree, methods and forms of interaction will be determined by the tasks users have to accomplish when using the visualization (Khuri, 2001).
1.1 Constructing learners' own input data sets.	(Foutsitzis & Demetriadis, 2008; Hundhausen & Douglas, 2002; Hundhausen, Douglas & Stasko, 2002b; Naps, Rößling, Almstrum, Dann, Fleischer, Hundhausen, Korhonen, Malmi, McNally, Rodger & Velázquez-Iturbide, 2002; Pears et al., 2007b; Yeh et al.,	Presenting problems that vary in relevant features allow learners to develop appropriate schemas by distinguishing between the relevant and irrelevant features (Wouters et al., 2008). Variety can be achieved by allowing the learner to provide different inputs to the algorithm so that the learner views repeated, but differing, visualizations of the same algorithm (McNally et al., 2007). If the algorithm animation is presented in discrete segments supplemented with explanations of the actions, so that students may pause according to their needs, while they may also provide their own data or	Data input facilities should be carefully constructed to focus learners' attention on the intended type of understanding (Rößling & Naps, 2002). The designer should set boundaries for the visualization, for example in the range and/or format of input allowed (Khuri, 2001). In selecting input data, it is better to start with smaller sets and allow for larger sets for users who understand the visualization. Possible erroneous input situations should be taken into account (Khuri, 2001). Canned data sets that cover the important cases in an algorithm significantly increases

Guideline	References	Reason/explanation	Considerations/Comments
References from CER are blue, from educational psychology pink, from computer graphics purple, expansions / additional guidelines green.			
	2006)	select between different sets of data, a flexible interface is provided for the learner (Hansen et al., 2002).	the pedagogical value of an AV, while allowing users to enter their own data sets does not provide significant pedagogical value, since they do not have the ability to choose good test cases (Saraiya, Shaffer, McCrickard and North, 2004).
1.2 Programming the target algorithm/ constructing through learners' own visualizations.	(Foutsitzis & Demetriadis, 2008; Hundhausen & Douglas, 2002; Hundhausen et al., 2002b; Naps et al., 2002; Pears et al., 2007b; Stasko et al., 1993; Yeh et al., 2006)	Experienced users may want to integrate their own programs into the system (Khuri, 2001).	
1.3 Making predictions regarding future visualization states.	(Foutsitzis & Demetriadis, 2008; Hundhausen & Douglas, 2002; Hundhausen et al., 2002b; Naps et al., 2002; Pears et al., 2007b; Rößling & Naps, 2002)	Expectancy-driven methods that require learners to predict the next step in a process in the animations encourage self-explanation that will assist integrating newly acquired knowledge within prior knowledge (Wouters et al., 2008).	
1.4 Answering strategic questions about the visualization, for instance searching for trends or structures; testing a hypothesis through interaction; or specifying a result that students should achieve by tinkering with the parameters of an algorithm.	(Foutsitzis & Demetriadis, 2008; Hundhausen & Douglas, 2002; Hundhausen et al., 2002b; Naps et al., 2002; Pears et al., 2007b)	If the system is intended for exploratory purposes, the interaction should encourage the user's search for structures, trends or testing a hypothesis (Khuri, 2001).	
1.5 Answering self-assessment exercises in the form of periodic questions, for example tickler and	(Foutsitzis & Demetriadis, 2008; Hundhausen &	Students may test their understanding through self-assessment exercises such as periodic tickler questions or questions that	Multiple choice questions at breakpoints between modules of the visualization should provide immediate feedback (Hansen et al.,

Guideline	References	Reason/explanation	Considerations/Comments
References from CER are blue, from educational psychology pink, from computer graphics purple, expansions / additional guidelines green.			
multiple choice questions, or questions that prevent the user from continuing without correct answers.	Douglas, 2002; Hundhausen et al., 2002b; Khuri, 2001; Naps et al., 2002; Pears et al., 2007b)	need to be answered before the animation proceed (Khuri, 2001), because interactive questioning forces them to stop and think about what they are viewing (McNally et al., 2007). Hansen et al. (2002) agree that random pop-up tickler questions in appropriate context without feedback, stimulate self-explanation. Interactive feedback will show students how well they understand the algorithm (McNally et al., 2007), while short quizzes can also help novices understand the material (Khuri, 2001).	2002). The interaction mechanism should be simple and forgiving. The designer should take care to reduce the possibility of errors, by. allowing reversal of actions, e.g. providing an 'undo' or 'redo' facility (Khuri, 2001).
1.6 Using sub-goaling to prompt learners to group coherent steps of a procedure into a meaningful sub-goal in the animation.	(Wouters et al., 2008)		
1.7 Asking learners to imagine procedures and concepts that are used in the animation.	(Wouters et al., 2008)	Studies have shown that imagining skills before performing them, leads to better performance (Wouters et al., 2008).	
1.8 Supporting dynamic feedback on the learner's activities in the system.	(Naps et al., 2002)		
28. Integrate visualizations into the course material.	(Ben-Bassat Levy & Ben-Ari, 2007; Lahtinen, 2006; Lahtinen et al., 2007a; Naps et al., 2002; Rößling, 2010)	Integrate the PAV tool with the study material to ensure that students accept and engage with it (Ben-Bassat Levy & Ben-Ari, 2007; Lahtinen, 2006; Lahtinen et al., 2007a; Rößling, 2010).	Allow students to use PAV voluntarily (Lahtinen et al., 2007a), since it can assist students with problems, but also have no value for students who already understand programming well (Lahtinen, 2006). Animations should be linked to specific instructional goals (Stasko et al., 1993), with relevant and appropriate information to achieve specific learning objectives (Hansen et al., 2002). The content of the AV should therefore be selected according to its intended purpose, and an assessment should be made to ensure that AV is the most

Guideline	References	Reason/explanation	Considerations/Comments
References from CER are blue, from educational psychology pink, from computer graphics purple, expansions / additional guidelines green.			
			effective way to present the information (Khuri, 2001). The decision to use a static or dynamic presentation of learning material, should be based on pedagogical grounds, for example, what would best support learners in mastering the study material (Chan & Black, 2005). Animation should only be incorporated into learning activities when the characteristics of animation are consistent with the learning task, for example in some situations multiple discrete diagrams may serve the purpose better than animations, since this can allow comparisons and repeated inspection of details (Taylor & Pountney, 2009).
29. Animations for teaching purposes should be of small scope.	(Taylor & Pountney, 2009)		
30. Animations should not be too complex.	(Taylor & Pountney, 2009)		
31. Use a general-purpose framework, such as a standard GUI to manipulate the tool, for instance similar to a Windows environment with which the user is already familiar.	(Bergin et al., 1996; Rößling & Naps, 2002; Yeh et al., 2006)	A general-purpose system that offers a common interface to a multitude of animations will make integration into a course easier (Rößling & Naps, 2002).	Choose the system's platform to allow the widest possible target audience (Rößling & Naps, 2002).
32. Students should be properly guided in how to use the PAV tool. This can be done by including a brief textual introduction and providing resources that help learners interpret the graphical representation that maps the visualization to the underlying algorithm by explaining it with text or narration, or reinforcing the relationship with instructional time during the course.	(Grissom et al., 2003; Hansen et al., 2002; Laakso et al., 2008; Naps et al., 2002; Yeh et al., 2006)		The situations where the visualization will be used also influence its design. Visualizations intended for self-study need much more explanatory cues than one that will be used in a classroom situation (Khuri, 2001).

Guideline	References	Reason/explanation	Considerations/Comments
References from CER are blue, from educational psychology pink, from computer graphics purple, expansions / additional guidelines green.			
Detailed instructions should be provided, in particular when a PAV tool is used in an ODL environment. It is highly recommended that a way should be found to compel users to work through the instructions for using the PAV tool before engaging with it for the first time.			
33. Use a conversational tone (using 'I' and 'you') in verbal or textual explanations.	(Mayer & Moreno, 2002)	According to the personalisation principle in the cognitive theory of multimedia learning, learners learn better from animation and narration when the narration is in conversational tone (using 'I' and 'you') since they are more involved and then work harder to understand the explanation (Mayer & Moreno, 2002).	
34. Include explanations in natural language synchronised with program state information. A text window, which is ideally always visible, audio track or hypertext explanation as well as pseudocode can be used for this purpose.	(Bergin et al., 1996; Holvitie, Rajala, Haavisto, Kaila, Laakso & Salakoski, 2012; McNally et al., 2007; Naps et al., 2002; Rößling & Naps, 2002; Stasko et al., 1993)		The spatial contiguity principle in the cognitive theory of multimedia learning asserts that on-screen text should be presented near to the part of the animation that it describes, to prevent wasting cognitive capacity in searching for the corresponding animation section (Mayer & Moreno, 2002). Taylor & Pountney (2009) also advise that textual explanation should be near the animation on the screen.
35. Use the contiguity principle. The contiguity principle in Wouters' (2008) guidelines based on cognitive load theory, states that verbal explanations in animations should be presented contiguously in time and textual explanation in the same space as the illustrative material, so that the explanation and the pictorial information are active in working	(Mayer & Moreno, 2002; Wouters et al., 2008)	Employing the contiguity principle should exclude the split-attention effect. The split-attention effect occurs when one source of information must be held in working memory while searching for another, because the two sources of information have to been integrated before it can be understood (Sweller et al., 1998).	Research regarding learners' spatial ability should be taken into account when the contiguity principle is applied, since this principle is affected by learners' spatial ability. Mayer and Sims (1994:392) define spatial visualization as "the ability to mentally rotate or fold objects in two or three dimensions and to imagine the changing configuration of objects that would result from such manipulations". Concurrent

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memory simultaneously. This corresponds with the spatial contiguity principle in the cognitive theory of multimedia learning, which asserts that on-screen text should be presented near the part of the animation that it describes, to prevent wasting cognitive capacity in searching for the corresponding animation section (Mayer & Moreno, 2002).			presentation of verbal and visual information benefits mainly learners with a high spatial ability, since they have a better ability to build mental connections between the verbal and visual representations (Mayer & Sims, 1994). Program code represents an abstract space that has to be navigated with the same cognitive strategies as used in natural environments (Cox et al., 2005). A strong positive correlation between students' spatial ability and their results in programming modules, with much lower correlations between their spatial ability and non-programming modules, has been found (Jones & Burnett, 2007). This seems to suggest that students with lower spatial ability struggle more with programming subjects. Students with a low spatial ability also use less effective navigational strategies when attempting to comprehend code (Jones & Burnett, 2007). Therefore, it seems as if using verbal explanations in animation, even if the contiguity principle is applied, might be to the disadvantage of weak programming students.
36. Apply the modality principle. Modality refers to the sensory mode in which verbal information is presented: written or spoken. In cognitive load theory the modality principle suggests that textual explanations in animations should be presented in spoken format, as this allows more information to be processed visually. Since the modality principle is not	(Wouters et al., 2008)	The modality principle is intended to decrease the extraneous cognitive load (Wouters et al., 2008). Taylor and Pountney (2009) also maintain that dual coding, where visual and auditory presentations are used together, may enhance comprehension. The cognitive theory of multimedia postulates that integration is most likely to occur when the corresponding pictorial and verbal representations are in working memory at the same time. Accordingly,	If dual coding is used, the animation and the narration should occur simultaneously (Taylor & Pountney, 2009). Although the modality principle is intended to decrease the extraneous cognitive load (Wouters et al., 2008), this may have a negative effect if the speaker has a foreign accent, since the additional effort to decipher the accent adds to the cognitive load (Mayer et al., 2003). Also, when learners have control over the

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always applicable, users should be allowed an option for auditory explanations in conjunction with textual explanations.		meaningful learning will be encouraged under instructional conditions that present pictorial and verbal information simultaneously. According to the temporal contiguity principle in the cognitive theory of multimedia, learners make better connections when corresponding narration and animation are presented simultaneously (Mayer & Moreno, 2002). The modality principle in the cognitive theory of multimedia maintains that learners learn better from animation and narration, than from animation and on-screen text, since the visual channel is less likely to be overloaded. That should provide more opportunity to build connections between corresponding words and pictures (Mayer & Moreno, 2002). The multimedia principle in the cognitive theory of multimedia, states that students learn better from both narration and animation than from narration alone, when the learner has to create the mental picture him- or herself (Mayer & Moreno, 2002). The redundancy principle in the cognitive theory of multimedia asserts that learners learn better from animation and narration, than from animation, narration and on-screen text. It is based on the same rationale as the modality principle (Mayer & Moreno, 2002).	pacing of the animation, written explanatory text is more effective than spoken explanatory text, since this allows the student more time to study the information. It is also much easier to move forwards and backwards through written text than through spoken texts, because the linearity of the spoken text makes it more difficult to follow when scanning through (Tabbers et al., 2004).
37. Avoid using extraneous material (words, sounds, video, and pictures) and reduce extraneous cognitive load as much as possible..	(Mayer & Moreno, 2002)	The coherence principle in the cognitive theory of multimedia learning states that extraneous material (words, sounds, video, and pictures) should be excluded to prevent wasting cognitive resources on irrelevant	

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		material (Mayer & Moreno, 2002).	
38. Support flexible execution control with direct-manipulation animation (DMA) where learners interact directly with the navigation controls (such as buttons and sliders) of an animation to determine the direction of their viewing themselves. They should be able to move both forward and backward at their own speed as well as to rerun and execute the visualization in smooth motion. A structural view of algorithm's main parts may be included to allow the student to jump directly to a specific key point in the animation without a search or having to cover steps that they understand. In smooth motion the animation should be well-paced.	(Bergin et al., 1996; Chan & Black, 2005; Hansen et al., 2002; Holvitie et al., 2012; McNally et al., 2007; Naps et al., 2002; Röβling & Naps, 2002; Saraiya et al., 2004; Stasko et al., 1993; Wouters et al., 2008; Yeh et al., 2006)	Flexible execution may create a flexible interface for the learner: When the algorithm animation is presented in discrete segments supplemented with explanations of the actions, students may then pause according to their needs. If they can also provide their own data or select between different sets of data, together this provides a flexible interface (Hansen et al., 2002). Learners need sufficient time and mental resources to process and understand the relationships between various components in the animation. DMA supports this by allowing them to control their viewing sequence in such a way that they can visualize how a change in one parameter affects other parameters in the dynamic system (Chan & Black, 2005). Tversky, Morrison & Betrancourt's (2002:258) *apprehension* principle states that "the structure and content of the external presentation should be readily and accurately perceived and comprehended." This means that the animation must be slow and clear enough to allow learners to perceive changes and to understand the changes in the relations between the different parts and the sequence of events. Pacing allows learners to control the tempo of presentation according to their own cognitive needs and therefore decreases the extraneous cognitive load, for example to reduce activities that impede learning (Wouters et al., 2008). Execution in smooth motion can help users	When learners have control over the pacing of the animation, written explanatory text is more effective than spoken explanatory text, since this allows the student more time to study the information. It is also much easier to move forwards and backwards through written text than through spoken texts, because the linearity of the spoken text makes it more difficult to follow when scanning through (Tabbers et al., 2004).

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		detect changes (Rößling and Naps, 2002).	
39. Divide the display area into functional areas that are consistently used for the different types of information.	(Khuri, 2001)	This prevents the display area from being cluttered (Khuri, 2001).	Important information should be placed near the top left, since eye-motion studies show that the human gaze goes to the upper-left of a rectangular display and then moves clockwise (Khuri, 2001).
40. Window management should allow all windows to be visible when the AV starts and might allow users to resize or reposition windows to suit the user.	(Saraiya et al., 2004)		
41. Care should be taken in deciding what information should be presented and how it should be done. An appropriate set of conventions in the form of the shape, size, colour, texture, sound and arrangement of objects to represent different information, should be developed and applied consistently.	(Khuri, 2001)	A user-centred design is important. Consistent locations for buttons, sliders and switches will minimise perceptual and cognitive demands on learners. Providing alternative interaction methods such as sliders, or arrows on the screen to advance or backtrack, or keyboard arrows, can accommodate different navigation styles or learning preferences (Chan & Black, 2005).	
42. Apply Tversky et al.'s (2002:257) *congruence* principle which states that "the structure and content of the external representation should correspond to the desired structure and content of the internal representation". The animation should therefore present the process or procedure in the same way and order that people visualize it. Use this as a means of consolidating mental models deliberately.	(Tversky et al., 2002)		
43. Use signalling, or cueing to draw the user's attention to critical areas of the visualization, for instance by using different colours, highlighting	(Bergin et al., 1996; Hansen et al., 2002; Taylor & Pountney, 2009; Wouters et al.,	Signalling assists meaningful learning, because it guides attention to relevant information and facilitates the efficiency of a visual search for the necessary information	Although people do not learn more from colour displays than from black and white displays, colour helps people to remember and is more enjoyable. A maximum of five

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algorithmic actions, underlining words or using arrows to focus attention on a specific part of the animation. Signalling or cueing should also be used judiciously to assist with navigation through the PAV tool, by providing clear indications on how to navigate through the PAV tool, without adding additional cognitive load.	2008)	(Ozcelik, Arslan-Ari & Cagiltay, 2010), thereby assisting the learner in selecting and organising the instructional material (Wouters et al., 2008).	colours, and preferably four only for novices, should be used to allow more short-term memory for information processing. Foveal (centre) and peripheral colours should be used appropriately, for example blue is suitable for large backgrounds, while red and green should be used in the centre of the visual field. Strong contrasts of colours on the opposite of the colour wheel should be avoided since this produces vibrations, illusions of shadows and afterimages. Use familiar colour coding such as red for stop or danger. The same colour should be used consistently for related elements to assist conceptual comprehension without verbal clues. Use bright colours to draw attention. Colour can save screen space by for example using a small area changing in colour to indicate progress, rather than a bar or line (Khuri, 2001). Non-speech sound can be used to draw the user's attention to an event. Since this may easily be an irritating feature, a flexible easily accessible user-configuration component should be included to allow users to specify the sound for each event and switching it on or off. Documentation, online training and examples should be given to prepare users for using this feature. The number of sounds should be restricted, as there is a threshold for the number of sounds that can be learned and remembered (Khuri, 2001).
44. Include pseudocode for the algorithm.	(Hansen et al., 2002; Naps et al., 2002; Saraiya et al., 2004)	Clear pseudocode should be provided to help the user relate state changes directly to algorithm's progress (Saraiya et al., 2004).	Saraiya et al. (2004) found that participants provided with a pseudocode display and a question guide (a series of questions meant

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			to guide users through AV and force them to engage with the content of the AV), spend substantially more time with the AV as compared to using simple AVs without these features. However, neither the pseudocode display nor the question guide appears to have had significant pedagogical benefit. Also, an analysis of learning time versus performance showed that a larger learning time does not mean participants understand the algorithm any better. This implies that providing the right set of features could reduce learning time, while using more features may result in increase in learning time with little pedagogical benefit. This finding contradicts Hundhausen et al. (2002) who suggest that more time spent with AV translates into more learning (Saraiya et al., 2004).
45. Pseudocode lines should be highlighted synchronously as the animation executes.	(Hansen et al., 2002)	This acts as a form of signalling or cueing, and may help the user relate state changes directly to algorithm's progress (Saraiya et al., 2004).	
46. Provide different views of the data, program or algorithm. This could include for example windows for both pseudocode and program animation, and both the logical and the physical view of a data structure as well as the distinction and connection between these views.	(Bergin et al., 1996; Hansen et al., 2002; Naps et al., 2002; Saraiya et al., 2004; Yeh et al., 2006)	Prompts to explore different views and different data sets encourage student interaction and demonstrates algorithm behaviour in more detail (Hansen et al., 2002). Multiple and multimodal representations, for example three distinct views of the animation may be used to demonstrate the algorithm behaviour – the analogy, a micro view with a small data set, and a macro view with a large data set (Hansen et al., 2002).	Multiple views of the same algorithm should be used judiciously to prevent information overload (Khuri, 2001).
47. Include capabilities for comparative algorithm analysis such as	(Bergin et al., 1996; Naps et al., 2002;	Prompts to explore the different algorithms or data sets may encourage user interaction	

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performance information that shows the algorithm's efficiency, or simultaneous identical views of different algorithms manipulating the same data.	Yeh et al., 2006)	(Hansen et al., 2002).	
48. Include the execution history so that learners can see previous steps.	(Naps et al., 2002)		
49. Adapt to the knowledge level of the user (the learner). For instance use a less complicated system for novices and base appropriate feedback on the assumed background knowledge of users, which should be made clear. The users' demographic background and reading ability should be investigated and taken into account before the design and development of the PAV is done.	(Naps et al., 2002; Saraiya et al., 2004)	No AV can cater for all possible users (Khuri, 2001). Animations intended for novices may have no benefits for students with prior knowledge (Lahtinen, 2006; Lahtinen et al., 2007a). Khuri (2001) stresses the importance of an analysis of the users, their needs, their tasks, the scope of the package and the resources available to developers. Novices need much more guidance in mapping the visualization to the program, as well as help in how to use the AV system, than experienced users. Short quizzes may help novices understand the material, while experienced users may want to integrate their own programs into the system (Khuri, 2001).	The effectiveness of a presentation format depends on the degree to which it matches the learners' cognitive and comprehension processes (Chan & Black, 2005). The effectiveness of Wouters et al.'s (2008) guidelines to manage cognitive load in animation depends on several mediating factors, notably learners' prior knowledge, spatial ability, motivation and the age of learner. Learners with high spatial ability benefit more from animations with verbal explanations than learners with low spatial ability. The pattern of cognitive load may be affected by motivation and self-efficacy. Also, the efficiency of working memory deteriorates with age. Design guidelines might also interact, for instance when pacing is used, modality should be adapted since learner pacing seems to cancel the advantage of verbal over written explanations. On the other hand, combinations of guidelines, such as signalling and modality, might be particularly effective (Wouters et al., 2008).
50. Scaffold learning with an animated analogy (for example illustrating merge-sort by sorting a deck of cards); pre-training; a sequence of simple-to-complex whole tasks, or segmentation.	(Hansen et al., 2002; Wouters et al., 2008)	Scaffolding decreases intrinsic cognitive load by reducing or managing the interactivity of the learning material (Wouters et al., 2008). Segmentation decreases the extraneous cognitive load, it for instance reduces	

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Simple-to-complex whole tasks allow learners to construct and automate schemas with low element interactivity and then gradually increase the complexity. Segmentation divides animations into several segments in which each segment presents an important part of a procedure or process.		activities that impede learning (Wouters et al., 2008)	
51. Perform user testing on each animation before using it for instruction to ensure ease of use.	(Saraiya et al., 2004; Stasko et al., 1993).	A pedagogically useful AV should have no usability and reliability concerns (Saraiya et al., 2004).	
52. The AV should be integrated with a database for course management reasons to allow tracking students' responses.	(Rößling et al., 2008; Rößling & Naps, 2002)		
27. Test the PAV tool stringently regarding the correctness of content, sequence of execution order, format and its didactical purpose.			
28. Educate users about the purpose of the PAV tool before they engage with it for the first time, to avoid unrealistic expectations and to ensure that they use it appropriately.			