FIRST-YEAR UNIVERSITY BIOLOGY STUDENTS' DIFFICULTIES WITH GRAPHING SKILLS

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DECLARATION

I declare that, apart from the assistance acknowledged, this research is my own unaided work. It is being submitted in partial fulfilment of the requirements for the degree of Master of Science at the University of the Witwatersrand and has not been submitted for any other degree or examination at any other university.

Horatius Dumisani Kali

30th day of January 2005.

ABSTRACT

Based on the perceived need for improved graphing skills of students at first-year university level, two lecturers wanted to produce a web-based computer programme to improve first-year university biology students' ability to construct and interpret graphs. Prior to designing and developing the package, however, it was important to establish whether there was a need for such a programme, and what might need to be included. The investigation to establish this provided the research described in this research report.

A *situation analysis* was conducted to establish the nature and extent of the problems of graphing skills discussed anecdotally in the staff room of biology departments at a number of institutes. The ultimate intention (beyond this study) was to determine whether the problems were extensive and serious enough to warrant developing supplementary teaching materials to teach graphing skills. All lecturers (n = 5) and teaching assistants (n = 4) involved in **using** or **teaching** graphing skills to first-year biology students at one university were identified and interviewed. The purpose of the interviews was to establish the problems they believed are exhibited by their first-year students (with reference to graphing skills), and the nature and extent of current teaching of such skills in their first-year courses. In order to triangulate the information on student's problems an item analysis was conducted of all questions incorporating graphs in two mid-year examination papers (n = 478 and n = 65), and students were observed during a practical session (n = 43).

Results revealed that students experienced fewer problems with interpreting graphs than with graph construction. Of the four categories of graph interpretation problems identified by the teaching staff, the most popular category was students inability to describe quantitatively what the graph is showing (4 teaching staff). This was confirmed in the question paper analysis when 58% of the medics students (n=478) were unable to answer correctly one question involving several interpretation skills. No specific skills for graph interpretation were observed as being a problem in the College of Science question paper (n=65). Observations showed interrelating graphs as the biggest problem (5 students out of 43). Five categories for problems with graph construction were identified by the teaching staff. The most commonly mentioned problem (4 teaching staff) was identifying or plotting variables, whereas class observation revealed scaling axes as the most problematic skill shown by students (15 out of 43). In the exams, 80% of the medics students could not correctly answer one question requiring multiple skills including identifying variables, and 56% could not correctly answer another question that required skills that also involved identifying variables. The College of Science question paper revealed that 85% of the students could not supply the units of measurement for the *y* axis.

A *needs analysis* was conducted to establish how the lecturers thought graphing skills should be taught and who should teach the skills. This information was needed to provide suggestions (from education "experts") about what could be included in the computer programme to be developed subsequent to the research study, and how the teaching could best be done. Four members of the teaching staff said it was important to give students a lot of exercises to practice the skills and five members of the teaching staff said it was the responsibility of the university tutors or lab staff to teach graphing skills.

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CHAPTER 1

CONTEXT OF THE STUDY AND INTRODUCTION TO THE PROBLEM

The study involved an investigation of first-year university biology students' problems with graphing, and what might need to be done to curb the problems. The investigation involved a **"situational analysis"**, the intention of which was to establish whether the procedural understanding of graphing skills was indeed a problem, and to determine the nature and extent of the problem. Information on the graphing problems experienced by first-year biology students at one university was sought by means of interviews with teaching staff, non-participant observation during a graphing practical, and item analysis of graphing-related examination questions. Simultaneously a **"needs analysis"** was conducted to determine what staff believed needed to be done in order to solve the problems. This study is intended to establish whether the problem of graphing skills is extensive and serious enough to warrant developing supplementary teaching materials to teach graphing skills, with the long-term goal being to improve the graphing skills of our first-year students.

Having acknowledged the importance of graphs, this chapter will look at the problems associated with graph construction and interpretation experienced by students of different age groups at varying cognitive levels of development, supported by evidence from previous work of independent researchers, in order to emphasize the importance of this study.

1.1 THE IMPORTANCE OF GRAPHS

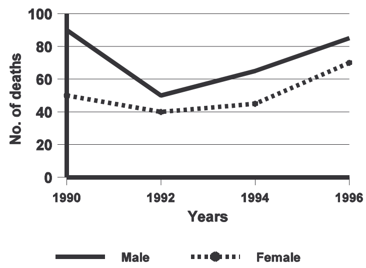
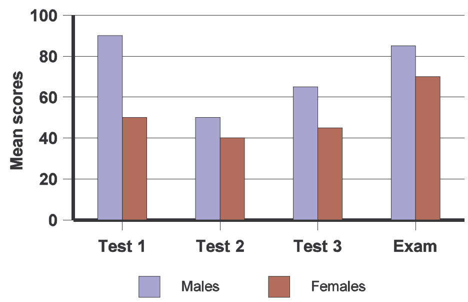
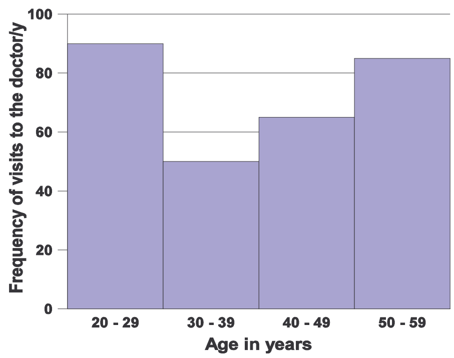
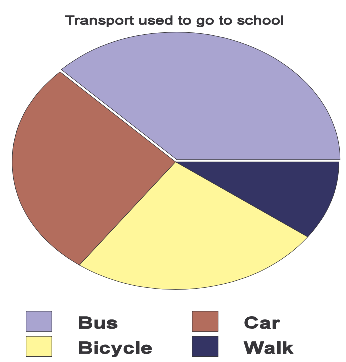
Brasell (1990:72) believes that *"graphing skills are so basic that they are included in standardized tests for measuring science-process, logical-reasoning, and problem-solving skills at all educational levels"*.

1.1.1 What are graphs?

A graph, also called a "chart", is defined as a "*drawing depicting the relation between certain sets of numbers or quantities by a series of dots, lines, etc., plotted with reference to a set of axes*" (Collins English Dictionary, 1991: 674).

There are a number of different types of graphs, and each has something different about it that makes it useful in a unique way. The type of graph used depends on the type of information which needs to be shown. Cleveland (1985) explains that both quantitative and categorical information can be used for graphing. The use of images makes a much more vivid impact than straight numbers. Graphs also have the capability to strengthen implications about data based on the type of graph, colors used, and other tools. Just because you see a graph does not mean you should believe it. Examine carefully where the data came from, and what it is telling you.Table 1 on page 2 summarizes the four commonest types of graph, and explains the situations in which it is appropriate to use each type.

Table 1. A summary of the four commonest types of graphs.

Type of graph	Example	Description
Line graph		Often portrays a time series data set, i.e. communicates a relationship through time. Best represents data that are values from continuous scales of measure.
Bar graph		Shows frequencies of discrete or categorical variables (ordinal or nominal data). Uses bars, stacked or side by side, to display data. The height of the bar represents the value of the variable measured.
Histogram		Shows frequencies of continuous variables. Similar to bar graph except that the edges of each bar must be on its class boundaries, i.e. must be touching or continuous.
Pie graph		Is represented as a circular diagram that looks like a pie cut into slices. The whole circle represents the whole amount of data being dealt with. Each slice represents the value of a variable measured. Useful for seeing the proportional relationship between components.

1.1.2 Why are graphs important?

Graphs are used for many different reasons, and can be found all over. Graphs can send a very powerful message to people. The importance of graphing competence in science is illustrated by the emphasis placed on graphing in many science curriculum projects (Berg & Smith, 1994; Padilla *et al.*, 1986).

Graphs are important for two main reasons.

- **They are a useful way of summarizing data.** Graphs can be used to show detailed results in an abbreviated form, displaying large amounts of information in a small space so that it can be viewed at a glance (Garvin, 1986; Brasell, 1990).
- **They communicate information in a way that is easy to interpret** (Rezba *et al.*,1998)**.** Graphs allow us to use our powerful visual pattern recognition facilities to see trends and spot subtle differences in shape (Mokros & Tinker, 1987). Graphs are powerful as a visual display of quantitative information (Tufte, 1983), which can often be read and understood more quickly and easily than the same data presented in narrative prose (Brasell, 1990; Hadley & Mitchell, 1995). Graphs can be a great help in interpreting the results of experiments because they show trends much more clearly than do tables (Ayerst *et al.* 1989). Garvin (1986: 11-12) claims that graphs "*give the observer a picture of facts and relationships which could not be understood so clearly, if at all, from verbal or tabular forms*". In addition to giving a clearer picture than the numbers in a data table they also show the relationship between the different variables being measured (Brasell, 1990; Stannard & Williamson, 1991).

The ability to work comfortably with graphs is a basic skill of the scientist (Beichner, 1994), and graphing skills are thought to be important in science scholars (Rogers, 1995). Several authors suggest that an inadequate mastery of graphing skills is a major stumbling block in understanding scientific concepts (Jackson *et al.*, 1993; Mokros & Tinker, 1987). Furthermore, because graphing is an important skill for adults, either in their professional jobs or simply as "consumers" of communication media, it has been recognised by educators as an important skill for science students (Jackson *et al.*, 1993). Linkonyane (work in progress) found that of the 526 first-year university students at a South African university who answered her questionnaire, 70% considered the ability to **interpret** graphs as "very important", and 28% as "important" for academic success in the biological sciences. The ability to **construct** graphs was considered slightly less important, with 51% of the students rating it as "very important" and 45% as "important". Thus 98% and 96% of the students, respectively, felt that graph interpretation and graph construction were important skills for academic success in university first-year biology.

1.1.3 Who uses graphs?

Graphs are a part of our daily existence because of their use in all media (Wavering, 1989), such as in newspapers, magazines, etc. (Berg & Smith, 1994). Schmid (1983) contends that graphing, or graphicacy, is an intellectual skill for the communication of relationships that cannot be communicated by word or mathematical notation alone. Furthermore, it is a skill needed by both those wishing to transmit the communication as well as those wishing to receive the communication. Adults use graphs to analyze and present data, whereas children are more likely to encounter them as aids to learning (Spence and Krizel, 1994). Three discrete audiences for graphs are:-

- **The man in the street** - who needs to be able to interpret the graphic information presented in the popular media, in order to be a thinking participant in society.
- **Professionals**, e.g. in business and industry - who need to be able to plot data in a meaningful way which allows them to see patterns and trends in sales and productions.
- **Scientists** - to allow them to communicate their findings, and to understand the work of others communicated in this way.

1.1.4 Graphing as process skills in modern science curricula

Science process skills can be roughly summed up as a set of broadly transferable abilities, appropriate to many science disciplines and reflective of the behaviour of scientists. According to Finley (1983: 48), *"they are the generalizable intellectual skills needed to learn the concepts and broad principles used in making valid inductive inferences"*. Mossom (1989), quoted by de Jager (2000: 37), defines science process skills as *"intellectual skills used by learners to process information"*. Science process skills can be grouped into two types, i.e. basic skills and integrated skills. These skills are hierarchically organised with the ability to use each upper level process dependent on the ability to use the simpler underlying process (Finley, 1983). In other words, the basic process skills provide a foundation for learning the integrated skills. These skills are listed and described below, based on the work of Finley (1983), Brotherton & Preece (1996), and de Jager (2000), and each skill which is important in constructing or interpreting graphs has been highlighted.

Basic science process skills are:

- *Observing* : Using the senses to gather information about an object or event. This can be described as the most basic process skill, as the development of the other skills are based on the ability to observe accurately (de Jager, 2000).
- *Inferring* : Making an "educated guess" about an object or event based on previously gathered data or information (Brotherton & Preece, 1996).
- *Measuring* : Using both standard and nonstandard measures or estimates to describe the dimensions of an object or event. *"Measurement enhances thinking by adding precision to observations, classifications and communications"* (de Jager, 2000: 44).
- *Communicating* : Using words or graphic symbols to describe an action, object or event. As mentioned earlier (Section 1.1.2), graphing is a very important skill for communicating data to others. According to de Jager (2000) recording, where learners use graphs, is also a form of communication.
- *Classifying* : Grouping or ordering objects or events into categories based on properties or criteria of the objects or events.

- *Predicting* : Stating the outcome of a future event based on a pattern of evidence. The ability to predict enables the learner to interpret some questions on graphing, which will show their understanding of the situation depicted by the graph.

These basic process skills can be considered as prerequisites for the integrated process skills. According to de Jager (2000: 38), *"integrated process skills are dependent of* (sic.) *the learner's ability to think on a high level and to consider more than one idea at the same time"*.

Integrated science process skills are:

- *Controlling variables* : Being able to identify variables that can affect an experimental outcome, and keeping most variables constant while manipulating only the independent variable. According to de Jager (2000), identifying variables refers to recognising constant characteristics of objects (the independent variables in the case of graphs), or characteristics that change under changing conditions (dependent variables in the case of graphs).
- *Defining operationally* : Stating how to measure a variable in an experiment (e.g. units in graphs).
- *Formulating hypotheses* : Stating the predicted outcome of an experiment.
- *Interpreting data* : Organizing data and drawing conclusions from it. In order to interpret data students need prior experience in making observations, classifying and measuring (de Jager, 2000), which are all basic science process skills. Results of an experiment could be presented in the form of graphs, which provide data that learners have to analyse and interpret in order to answer questions posed.
- *Experimenting* : Being able to conduct an experiment, including asking an appropriate question, stating an hypothesis, identifying and controlling variables, operationally defining those variables, designing a "fair" experiment, conducting the experiment, and interpreting the results of the experiment.
- *Formulating models* : Creating a mental or physical model of a process or event.

Graphs feature prominently among these science process skills, both in the basic process skills (e.g. communicating could be by means of graphs to explain and relate ideas and information), and in the integrated process skills (e.g. interpreting data could involve organizing data in a graph and drawing conclusions from it).

According to Tamir and Amir (1987), it is important to emphasise that the knowledge required in order to be able to apply science process skills should not be assumed to just happen. Instead, teachers need to devote time and effort to explicitly teach these skills. Tamir and Amir (1987) warn though that learning how to interpret a graph does not necessarily mean that a student knows how to construct a graph. These are two separate skills and each requires special attention and has to be taught in its own right. Science teachers need to provide opportunities for the development of each of these skills.

Finley (1983) believes that conceptual knowledge results from the application of science processes in understanding natural phenomena and solving problems. Formal reasoning and integrated science process skills share much in common, and methods used to enhance science process skills might be equally applicable to promoting formal reasoning ability, and vice versa (Baird and Borich, 1987). In their investigation of the effects of emphasising processes skills in teaching science among Year 7, 8 and 9 students, Brotherton and Preece (1996) found that a 28-week intervention was effective in promoting science process skills, as evidenced by the positive effects on cognitive ability of the students ten weeks after the intervention.

Procedural knowledge or know-how is the knowledge of how to perform some task, which is different from other kinds of knowledge such as propositional knowledge (knowing what) in that it can be directly applied to a task. For example, procedural knowledge about constructing graphs differs from propositional knowledge about graphs. One advantage of procedural knowledge is that it can involve more senses, such as hands-on experience, practice at solving problems such as constructing graphs from given data or interpreting graphs, understanding of the limitations of a specific solution, etc. Millar *et al.* (1994) subdivide procedural knowledge into three categories, viz.

- *Manipulative skills* - use of instruments and ability to carry out standard procedures. These types of skills are learned through drill and practice.
- *Frame* - understanding of the nature and purpose of an investigation task. This includes modelling (trying to do something) and engagement (manipulation of apparatus with no clear purpose).
- *Understanding of evidence* - e.g. many children seem prepared to draw conclusions on the basis of evidence that could be regarded as unreliable, or invalid, or both.

Constructing and interpreting graphs would fall into the first category of procedural knowledge. According to Millar *et al.* (1994), carrying out a scientific investigation (which can involve constructing or interpreting graphs) is a display of understanding, not of the skill, hence practice alone is not enough for children to be competent. What South African teachers seem not to understand is the need to emphasize teaching those elements of understanding which support expert performance.

1.1.5 Skills needed to construct and interpret graphs

Berg and Philips (1994) identify two critical attributes of graphing skills, i.e. the ability to **construct** and the ability to **interpret** graphs.

Interpreting graphs

Brasell (1990, 72) points out that

> "*as with any system of representing and communicating information, we attach meaning to graphs according to a set of rules or grammar. To read or interpret graphs, we must have*

at least an implicit understanding of this grammar".

Intepreting graphs involves two specific processes - **visual perception** (the ability to see what is shown by the graph in terms of shape, the elements shown etc.) and **graphic cognition** (the ability to convert the information seen into meaningful information). The sorts of skills needed in order to **interpret** graphs include the following:

- determining the X and Y coordinates of a point (Padilla *et al.,* 1986; Brasell, 1990),
- establishing what is being represented on each axis, and looking at the units and how they quantify the data (Brasell, 1990),
- interpolating and extrapolating (Padilla *et al.,* 1986; Brasell, 1990),
- giving logical meaning by applying the appropriate "grammar" provided by the graph schema in long-term memory for decoding information in the graph (Brasell, 1990),
- understanding the meaning of the shape of the graph in describing how one variable relates to another (Padilla *et al.,* 1986; Brasell, 1990),
- determining salient features of the graph (influenced by innate attributions of the graph and by previous experience), i.e. understanding how to link the graph with the variables or with phenomena in the real world (Brasell, 1990).
- extracting essential information from a given graph, and explaining trends shown in the graph in terms of content knowledge (Brasell, 1990),
- interrelating the results of two or more graphs (Padilla *et al.,* 1986; Brasell, 1990).
- predicting changes in trends when a variable is manipulated (Brasell, 1990),

Constructing graphs

Brasell (1990:72) points out, however, that to ***construct graphs*** more is needed - the grapher's knowledge has to be "*conscious and explicit*". Skills needed for graph **construction** include the following:

- selecting the appropriate type of graph to plot from any given data, i.e. identifying continuous and discontinuous (discrete) data and deciding which type of graph to use (Brasell, 1990). According to Tamir and Amir (1987), the skill of selecting the form of presenting findings is an important skill often neglected by science teachers even though it appears to warrant special attention.
- assigning dependent and independent variables to the correct axes (Padilla *et al.,* 1986; Brasell, 1990),
- choosing the appropriate axes on a graph with more than one y-axis (Brasell, 1990),
- drawing and scaling axes (Padilla *et al.,* 1986; Brasell, 1990),
- plotting points on a graph from data provided in tabular form (Padilla *et al.,* 1986; Brasell, 1990),
- constructing a line of best fit (Padilla *et al.,* 1986; Brasell, 1990),
- providing a suitable title for a graph,

- correctly annotating a graph (or providing a legend/key).

1.2 THE PROBLEM WHICH MOTIVATED THIS RESEARCH

Nowadays children and adults are bombarded by a deluge of information in their everyday lives, often in the form of large amounts of data. In order to make sense of this wealth of information, graphs are often a useful form of representation because they display the data in such a way that general tendencies and the relationship between the variables is immediately evident to people able to interpret graphs. By the time students enter college, educators generally assume that students are competent in graphing, among other science process skills. Although graphing "*along with literacy, numeracy, and articulateness, ... is considered one of the basic skills*" (Balchin, 1972, cited by Brasell, 1990), it is well documented that students often lack even the most basic graphing skills (e.g. Mokros & Tinker, 1987; Wavering, 1989; Brasell, 1990).

According to Padilla *et al.* (1986), creating graphs and interpreting data from them are skills not easily acquired by most students. Phillips (1997), cited by Tairab and Khalaf Al-Naqbi (2004:130) states that *"Drawing general conclusions from graphs requires students to use multiple strategies to identify common trends and relate the variables involved, a procedure involving higher-level skills"*. Widespread student difficulty with regard to the interpretation and construction of graphs is reported by Padilla *et al.* (1986: 25), who call for "*... more training beyond the plotting of points, especially if we intend to use graphs for interpreting information in high school science courses*".

Brasell (1990) identifies three main types of difficulty experienced with graphing:

- lack of understanding of the concepts being represented (subject content knowledge),
- lack of knowledge about the rules and grammar of graphing, or lack of ability to apply this procedural knowledge,
- and problems linking the graph with the variables or what they show.

These difficulties will more often than not lead to a range of problems, as indicated by a number of researchers. Fifteen papers that reported difficulties in graphing were reviewed for this study. A summary indicating country, sample details and methods is given in Table 2 (starting on page 9), to help readers interpret/ understand the context and methodology of each study, so that they can decide how generalizable the results might be. Detailed results for fourteen of the studies are then summarized in Table 3 (starting on page 12). A discussion of the problems emerging from the literature reviewed follows the tables, starting on page 14.

Table 2. Summary of the papers dealing with graphing problems, reviewed for this study.

Authors and year	Country	Purpose of the study	Sample details	Methods
Bryant & Somerville (1986)	Great Britain	To determine whether children can find the y axis value if given the x axis value on a graph, and whether the fact that they have to extrapolate non-perpendicular lines in graphs causes them particular difficulty.	32 students from the same school, • 16 six-year olds (8 boys & 8 girls) • 16 nine-year olds (8 boys & 8 girls).	• Children were shown two different graph-like displays in each of which a straight line was drawn through the origin, one at an angle of 56 degrees and the other 34 degrees • A position was given on one axis and the child had to find the corresponding position on the other axis by extrapolation.
Padilla, McKenzie & Shaw (1986)	USA	To examine the line graphing ability of middle & high school students in order to provide baseline data on the mastery of line graphing subskills.	625 students, Grades 7 to 12.	The Test of Graphing in Science (TOGS) was used to measure graphing ability. No details of the test were provided in the paper.
Brasell (1987)	USA	To assess the effect of a very brief kinematics unit on ability to translate between a physical event and the graphic representation of it, and the effect of real-time graphing as opposed to delayed graphing of data.	93 students, mostly seniors with an average age of 17.7 years.	• Two treatment groups were used (i.e. a standard micro-computer based laboratory [MBL] activity using real-time graphing was compared with one where the display of data was delayed until after all the data has been collected). The only difference between these two treatments was the real-time vs delayed graphing of the data points • Control groups performed pencil-and-paper activities that parallelled the MBL treatments.
McDermott, Rosenquist & van Zee (1987)	USA	To investigate students' difficulties in connecting graphs to physical concepts and difficulty in connecting graphs to the real world.	Several hundred university students (details not given) in a descriptive study extending over a period of several years.	<u>Connecting graphs to physical concepts</u>: Test items checked for - • Discriminating between the slope and height of a graph • Interpreting changes in height and changes in slope • Relating one type of graph to another • Matching narrative information with relative features of a graph • Interpreting the area under a graph <u>Connecting graphs to the real world</u>: Test items checked for - • Representing continuous motion by a continuous line • Separating the shape of a graph from the path of the motion • Representing a negative velocity on a *velocity* vs *time* graph • Representing constant acceleration on an *acceleration* vs *time* graph • Distinguishing between different types of motion graphs.
Mokros & Tinker (1987)	USA	To determine how middle school children's graphing skills develop over the course of three months' work with micro-computer based laboratory (MBL) in science class.	125 Grade 7 and 8 children.	• A multiple-choice test of graphing skills • A "think-aloud interview".

Authors and year	Country	Purpose of the study	Sample details	Methods
Adams & Shrum (1990)	USA	To investigate the effects of microcomputer-based laboratory exercises & level of cognitive development on students' ability to construct and interpret line graphs.	20 students (10 males & 10 females) selected from a total of 46 students enrolled in general biology classes at a rural high school.	• Students were individually interviewed about graphing strategies • The Group Assessment of Logical Thinking (GALT) instrument was used to divide students into high & low cognitive development groups • Students were assigned to experimental and control groups based on their scores on the Test of Graphing in Science (TOGS) so groups were balanced on level of cognitive development, graphing skills and gender.
Beichner (1990)	USA	To see if viewing a computer-animated event of videotaped images, synchronised with a graph of the occurrence, results in better understanding than the traditional kinematics lab experiments.	237 students (165 from high school - average age 17.4 years, and 72 college - average age 24.0 years).	• Students were randomly assigned to experimental and control groups, but selected their own smaller working teams. • The exercise occurred in a 2-hour lab session. • Test of Understanding of Graphs - Kinematics (TUG-K) was used as pre- and post-test. • A two-way ANCOVA was performed on the post-test scores, using pre-test results as the covariate.
Brasell & Rowe (1993)	USA	To examine two specific factors that would influence students' ability to comprehend kinematics graphs of constant velocity events, viz. (i) the direction of translation and the type of verbal description used, (ii) explicit understanding of the grammatical conventions associated with Cartesian graphs.	93 Grade 12 students	The students • completed the French V-1 verbal test to assess verbal ability, and the Inventory of Piagetian Development Tasks to assess development and reasoning ability • responded to a 6-item Likert-scale questionnaire that focussed on students' perceptions of utility and difficulty as well as their interest in graphs • did a computer-administered Interpreting Graphs Test to determine graphing ability • completed a kinematics graph test after a single class period treatment.
Beichner (1994)	USA	To test student interpretation of kinematics graphs.	524 students at high school and college level (no details provided).	• A "Test of Understanding Graphs in Kinematics (TUG-K)" to identify problems with interpreting kinematics graphs was developed, and piloted with 134 college students who had been taught kinematics • Revised tests were then distributed to 15 science educators to establish content validity • A final version of the test was given to 524 college & high school students.
Berg & Phillips (1994)	USA	To investigate the relationship between logical thinking structures and the ability to construct and interpret line graphs.	72 students (20 Grade 7, 21 Grade 9 and 31 Grade 11) balanced by gender, and high and low academic prowess.	Students were interviewed on graphing (to assess what they can do regarding graph construction and interpretation) and Piagetian tasks (to assess logical thinking).
Berg & Smith (1994)	USA	To assess students' abilities to construct and interpret line graphs: Disparities between multiple-choice and free-response instruments were looked at.	n = 1416 (50% male, 50% female) from Grades 8 to 12, from high, medium, and low ability groups, and from both public & private schools.	Subjects completed either the multiple-choice or the free-response instrument on constructing and interpreting line graphs.

Authors and year	Country	Purpose of the study	Sample details	Methods
Spence & Krizel (1994)	Canada	To explore the possibility that children may judge some attributes of graphical elements differently from adults and, in particular, that they may exhibit biases in their estimates of the sizes of objects that older subjects have learned to suppress or correct.	Experiment 1 n = 20 subjects. • 7 Gr. 5 males • 2 Gr. 5 females • 7 Gr. 6 males • 4 Gr. 6 females Experiment 2 18 Gr. 4 and 25 Gr. 6 students: • 11 Gr. 4 males • 7 Gr. 4 females • 16 Gr. 6 males • 9 Gr. 6 females	Experiment 1 • The subject was shown a bar graph on a page with 2 bars, one shaded and one not, and a horizontal line that represents a whole • They were then asked to estimate where to divide the line to give the same proportions as the 2 parts of the graph • The procedure was repeated for different types of graphs (lines, bars, boxes and pies) Experiment 2 • Proceeded as for expt. 1 but used pies, separated pies, bars, and divided bars • Students were instructed to pay attention to boundaries and axes of symmetry in the graphs as points of reference • With pies they had to compare the graph angles to 90, 180, or 270 degree angles (equivalent to 1/4, 1/2 and 3/4 of the pie) • With the bars instructions were the same as with divided bars.
Mevarech & Kramarsky (1997)	Israel	To investigate students' conceptions and misconceptions relating to the construction of graphs.	92 Gr. 8 students (44 girls and 48 boys) randomly selected from two schools.	• Students were asked to construct graphs representing each of four given situations • Each student was given four blank sheets, each sheet with one problem printed at the top • Students were allowed to construct the graphs without a ruler • Students were examined prior to and following the learning of a unit on graphing skills • All students learned the unit by using the same textbook for the same duration of time • Teachers at both schools employed the traditional form of instruction (using the questioning-answering technique).
Ates & Stevens (2003)	USA	To explore two ways of teaching line graphs and to compare line-graphing skills of tenth-grade students of different cognitive developmental levels.	45 Gr. 10 students from two advanced chemistry classes in a public high school.	• Treatment 1: 22 students completed a line-graphing unit with computer-supported activities • Treatment 2: 23 students completed a line-graphing unit with non-computer-supported activities • Individualised Test of Graphs in Science (I-TOGS) and a Performance Assessment Test (PAT) were used to assess line-graphing skills of students.
Tairab & Khalaf Al-Naqbi (2004)	UAE & Brunei [1]	To investigate how secondary school biology students interpret and construct scientific graphs.	94 Gr. 10 students (15-16 yrs) from two secondary schools.	Quantitative analysis • Seven problems that required students to interpret graphical situations • Four problems that required students to construct graphs Qualitative analysis A random sample of fourteen students was interviewed.

[1] UAE = United Arab Emirates

Table 3. Summary of the results from the papers dealing with graphing problems, reviewed for this study

Authors and year	Results
Bryant & Somerville (1986)	Did not report the number of children who could or could not do the task. Results were reported as proximity to desired point (mean for group). Their (over-generalised) conclusions were that children: • were able to find the point on one axis corresponding to a given point on the other. • had no problem extrapolating a line which begins as non-perpendicular to the nearest marked line (line-to-axis extrapolation).
Padilla, McKenzie & Shaw (1986)	• Mean scores on the graphing skills test improved significantly from Grade 7 to 12, although improvements year by year were not significant. • The percentage of students who had mastered each skill were; plotting points (84%), determining the X and Y coordinates of a point (84%), interpolation and extrapolation (57%), describing relationships between variables (49%), interrelating graphs (47%), assigning variables to axes (46%) , scaling axes (32%), and using a best fit line (26%).
Brasell (1987)	Students where the graph was plotted (on the computer) as each data point was entered understood kinematics significantly better at the end of one lesson than students where the computer plotted the graph only after all data points had been entered, or the students doing pencil-and-paper graphing; even after ANCOVA was used to adjust pretest differences between groups.
McDermott, Rosenquist & van Zee (1987)	No frequencies were given regarding students who had a particular problem. All results were generalised • Students did not know whether to extract information about speed from the slope or the height of a graph. • Students found it more difficult to interpret curved graphs than straight-line graphs. • Students often could not relate position, time and velocity graphs to each other. • Many students had a problem matching a narrative passage to an accompanying graph. • Students had major problems in interpreting the area under a curve. • Students struggled to relate a graph to objects or events in the real world, e.g. position or time graph of a moving ball (Students tried to sketch graphs which mirrored the shape of the track). • Students struggled to construct graphs of uniform motion with data observed in the laboratory. • Some students did not join points in a smooth curve but made point-to-point connections.
Mokros & Tinker (1987)	There was a significant improvement in students' ability to interpret and use graphs after a three-month intervention, e.g. • in one of the hardest items, the graph-as-picture misapplication, only 13% of the students scored correctly on the pre-test, and in the post-test 77% of the students scored correctly. The graph-as-picture problems were resolved for most students by the micro-computer based laboratory intervention • in the "back-to-the future" graph (a graph that goes backward in time), 13 of 40 students scored correctly at pre-testing, while 23 of the 40 did so on the post-test.
Adams & Shrum (1990)	• There was no effect ($p = 0.01$) after the one hour intervention on the graph **interpretation** abilities of the students • However, students who did the MBL exercises outperformed the conventional students on graph **constuction** tasks ($p < 0.01$) • High cognitive development students scored better than low students for both graph construction and interpretation tasks.
Beichner (1990)	• After the two-hour intervention exercise, statistical analysis with the pre-test as covariate showed that the group doing the micro-computer based laboratory exercises did no better than the other group, although the highest post-test scores were achieved by the "computer" students. • Males scored significantly higher than females on both the pre-test ($p = 0.028$) and the post-test ($p = 0.015$), but neither gender learned more than the other ($p = 0.36$).

Authors and year	Results
Brasell & Rowe (1993)	• 14 out of 93 students claimed that they only use graphs when they perceive some need or benefit • Most students reported that they have little difficulty in constructing and interpreting graphs on the *Interpreting Graphs Test*. • Graphing abilities were significantly correlated with both *verbal ability* and *reasoning and development* scores ($p = 0.001$). • In constructing graphs, 75% of the students got the data points correct but only 51% got the scale right; only 35% could correctly identify the axes and label the graph, and only 6% could draw the line of best fit correctly.
Beichner (1994)	The students were unable to interpret kinematics graphs convincingly, as indicated by the mean test score of 40% on the test, taken after instruction in kinematics graphs.
Berg & Phillips (1994)	• Of the five Piagetian tasks examined, students passed only 2 tasks (57% of the students passed one task & 67% of the students passed the other) and failed the other 3 tasks (35%; 18% & 32% of students passing). • Students who showed development of Piagetian mental structures outperformed those who did not, e.g. those who passed the proportional reasoning task had a higher percentage of correct answers on 90% of all the graphing questions, and the results were similar for the other structures. • The percentage of Gr. 7, 9 & 11 students "passing" each construction test were: labelling axes (50%, 52%, 39%), ordering axes (55%, 91%, 97%), scaling axes (10%, 48%, 65%), connecting points correctly (15%, 52%, 45%). (0%, 29%, 32%) of the students in the three grades could do all tasks correctly. • Several tasks for interpretation abilities were given and results of only 3 are reported here as examples. In one graph the percentages of students with all 3 items tested for slope vs height correct were (20%, 38%, 23%). For "rate of change" graphs (30%, 29%, 26%) and for a graph on crops harvested (30%, 24%, 66%) got all the answers correctly.
Berg & Smith (1994)	• For the "walk-to-the-wall-and-back" graph, the free-response students performed significantly better than the multiple-choice students (56% correct graphs drawn, compared to 37% correct answers chosen). • For the "ball-on-a-hill" graph the free-response students drew 55% of the graphs correctly and the multiple-choice students chose correctly only 50% of the answers. • For the "bike-on-the-hill" graph the multiple-choice students scored 10% more correct responses than free-response students. • The high ability students performed at a level significantly above that of the middle and low ability students.
Mevarech & Kramarsky (1997)	*Qualitative analysis:* • Three major categories of problems were identified, i.e. constructing an entire graph as one single point (some students constructed the axes correctly but marked only one point, one bar, or one histogram); constructing a series of graphs, each representing one factor from the relevant data (some students could not conceive more than one factor at a time); and conserving the form of an increasing function under all conditions (some students conserved the shape of an increasing line by changing the scale of one axis to include only one value, the value of the constant. Others represented the graph by marking the value of the constant on an invisible line). *Quantitative analysis:* • On the pre-test, 26 students (27%) constructed all four graphs correctly and 60% constructed at least one graph correctly • On the post-test the number of students who constructed all four graphs correctly increased from 27% to 45% after being taught four times a week for three weeks.
Ates & Stevens (2003)	• After a three-week intervention, there was no significant difference in scores between students who received line-graphing instruction with computer-supported activities and students who received instruction with non-computer-supported activities. • Formal reasoning students scored higher than concrete reasoning students.

Authors and year	Results
Tairab & Khalaf Al-Naqbi (2004)	*Interpretation problems:* • When asked to draw general conclusions from five interpretation problems, 55.3%, 55.3%, 62.5%, 76.8% and 80.4% of the United Arab Emirates students were able to do this correctly, and 84.2%, 65.8%, 63.2%, 68.5% and 84.2% of the Brunei students .*Construction problems:* • 33.9%, 41.1%, 41.1% and 51.8% of the United Arab Emirates students drew four types of graphs correctly, whereas 42.2%, 63.2%, 76.3% and 71.1% of the Brunei students drew the same graphs correctly. • The authors attributed the fact that the Brunei students performed significantly better than UAE students to the better mathematical background and opportunities for practising graphing skills of the Brunei students.

It should be noted that not all of the summarised studies were on graph construction and graph interpretation. One study was on understanding depending on interpretation, three studies looked at intervention and did not identify the problems. Nine studies were looking at graph interpretation problems and seven at graph construction problems. It is also important to point out at this point the predominance of American studies, which might have a bearing on conclusions drawn. Of the fifteen studies reviewed, eleven were carried out in the USA. Also of importance is the fact that most of the studies reported here were looking at kinematics graphs, which are very difficult compared with the types of graphs used in biology, as observed by Brasell and Rowe (1993). Only two studies looked at the percentage of students mastering certain graphing skills.

The problems encountered can be grouped into four main types. The first type (see section 1.2.1) is difficulties in constructing graphs, which seems to correspond with the second type of difficulty identified by Brasell (see p.8), as most of them are a result of students not knowing the rules. The second type (see section 1.2.2) is difficulties in interpreting graphs. The third problem encountered in the literature is lack of awareness of graphing problems (see section 1.2.3). The fourth problem (discussed in section 1.2.4) is lack of ability to transfer skills taught in one subject to other subjects, which could be the result of the first type of difficulty identified by Brasell (see p.8).

Recent studies have indicated that students' understanding of graphs is rather limited (Mevarech & Kramarsky, 1997). Graphing involves both interpretation and construction. According to Mevarech and Kramarsky (1997), most students fail to understand that interpretation usually refers to students' ability to read a graph and make sense or gain meaning from it, whereas construction refers to the act of generating something new, i.e. going from raw data and building a graph or plotting points from data.

1.2.1 Difficulties in constructing graphs

Tamir and Amir (1987), in their investigation of the interrelationships among laboratory process skills in biology of 3,650 Grade 12 Biology students in Israel, found that the skill of constructing graphs as a form of presenting findings was an important skill often neglected in school curricula. A number of studies have identified problems in constructing graphs, by both secondary and tertiary level students (Padilla *et al.,* 1986; McDermott *et al.,* 1987; Brasell & Rowe, 1993; Berg & Phillips, 1994; Berg & Smith, 1994; Mevarech & Kramarsky, 1997).

- **Drawing, labeling and scaling axes.** Several studies in the USA concur that secondary school children have problems with drawing, annotating and scaling axes. In their study, Padilla *et al.* (1986) found that only 32% of the 625 secondary level students were able to scale axes. Brasell and Rowe (1993) found in their study that only 35% of the 93 Grade 12 students could correctly identify the axes and 51% got the scale right. Of the 72 students studied by Berg and Phillips (1994) only 50%, 52% and 39% of the students from Grades 7, 9 and 11 respectively labelled the axes correctly, and 10%, 48% and 65% of the students correctly scaled the axes.

- **Constructing a line of best fit/interpolating.** A number of researchers in the USA have found constructing a line of best fit to be one of the biggest problems that students ranging from Grade 7 up to university have. In one study, only 26% of the 625 secondary level students investigated could use line of best fit (Padilla *et al.,* 1986). In another study, Brasell and Rowe (1993) found that only 6% of the students could draw the line of best fit correctly. Berg and Phillips (1994) found that only 15%, 52% and 45% of the students from Grades 7, 9 and 11 could connect points correctly. McDermott *et al.* (1987) found that some university students (numbers not given) made point to point connections and did not join the points in a smooth curve.

- **Failure to graph the relevant variables.** A problem reported, but not widely documented, is students' inability to assign variables to the correct axes. Padilla *et al.* (1986), in their examination of the line graphing ability of middle and high school students found that of the 625 students tested, only 46% could correctly assign the variables. School students in the USA were

  > *"unable to determine which variables from a data set are relevant to the task or how to assign the variables to the appropriate axes.....and have a tendency to place time on the x-axis when plotting graphs, regardless of the data set provided"* (Brasell, 1990: 80).

  In their study of 94 Grade 10 biology students from two different schools, one in Brunei and the other in the United Arab Emirates, Tairab & Khalaf Al-Naqbi (2004) found that some students could not see the relationship between the dependent and independent variables and how they should be plotted on the axes.

- **Failure to understand whether to obtain information from the slope or height of the graph.** Some studies have revealed that some students have a tendency to confuse distance and speed when constructing time graphs. Separate studies by McDermott *et al.* (1987) and Brasell (1990) in the USA found that students confused velocity and acceleration graphs and constructed a velocity-time graph that has the same shape as a distance-time graph. It was difficult to determine whether this was due to problems with graphs or due to problems with the concept (McDermott *et al.*, 1987).

  - **The "graph-as-picture" misconception / "picture of the event" phenomenon.** Occasionally some students tend to draw a picture of what is described in the question. In problems dealing with balls rolling in tracks or people riding bicycles over hills, students using "graph-as-picture" often drew velocity-time graphs resembling the shapes of the tracks or hills, rather than showing the velocity of the ball or bicycle (Brasell, 1990; Berg & Smith, 1994). According to Brasell (1990), these students do not understand the fundamental purpose of displaying the data in a graph.

  - **The "back-to-the-future" misconception.** Sometimes students do not know which variable goes to which axes. When asked to construct a graph to represent the movement of an object from point

A to point B and back, students produced a graph that resembled the path of the object. This probably results from graphing the wrong variables, and/or plotting variables on the wrong axis. These students failed to understand that in such a situation both axes of a Cartesian graph represent continuous variables, i.e. there is a tendency to treat data points along the x-axis as discrete units (categorical variables) as in bar charts (Brasell, 1990). This may account for many scaling errors in graph construction and in interpolating and extrapolating (Padilla *et al.,* 1986). Sometimes students represented a stationary object as a point on a time-course graph rather than as a continuous line, because they failed to realize that time advances even when other variables remain constant (Mokros & Tinker, 1987; Brasell, 1990).

- **Determining the x and y coordinates and plotting points.** There is generally very little evidence to show that students struggle with finding the coordinates of a point. Padilla *et al.* (1986) found that 84% of the 625 secondary level students could determine correctly the x and y coordinates of a point and plot points correctly.

1.2.2 Difficulties in interpreting graphs

Students at all age levels have difficulties with graph interpretation (Berg & Phillips, 1994). The problem of students' lack of graphing skills seems to be a global phenomenon. For example, Beaton and Robitaille (1999) documented that the Third International Mathematics and Science Study (TIMSS), which was carried out in over 40 countries in 1995 at five different grade levels, with over a half-million students, found that in data representation many students had difficulty moving beyond a straightforward reading of graphs. According to Beichner (1994), there is ample evidence that difficulties in interpreting graphs, are widespread, and manifest at all levels of education (Padilla *et al.*, 1986; Wavering, 1989). Several studies listed below have shown that reading off information from a graph can be a problem for students at different age levels (Padilla *et al.*, 1986; McDermott *et al.*, 1987; Mokros & Tinker, 1987; Brasell, 1990; Beichner, 1994; Berg & Phillips, 1994; Tairab & Khalaf Al-Naqbi, 2004).

- **Failure to recognize quantities that cannot be determined from a graph.** Sometimes some information cannot be read directly from a graph. When interpreting line graphs for instance, some university students in the USA (details not given) did not realize that it is impossible to tell an object's starting point from a velocity-time graph, as well as whether an object is accelerating or decelerating from an acceleration-time graph (McDermott *et al.*, 1987).

- **Difficulty relating a graph to another representation of the same information.** Occasionally students fail to make connections between a graph and the same information presented in narrative prose. In one high school in the USA students had problems matching verbal and graphic information, and integrating mathematical equations with graphic representations (Brasell, 1990).

- **Distinguishing between slope versus height.** Secondary school students usually have big problems with slope versus height graphs. Berg and Phillips (1994) found that only 20%, 38% and 23% of the students from Grades 7, 9 and 11 respectively (n=72) could correctly do all three tasks given to distinguish between slope versus height.

- **Interrelating graphs.** High school students usually cannot make relations between two or more graphs. Padilla *et al.,* (1986) found that only 47% of the 625 secondary level students could relate one graph to another.

- **Determining salient features of the graph.** Sometimes students do not understand the actual purpose of a graph. Students failed to understand how to link the graph with the variables or with phenomena in the real world (McDermott *et al.*, 1987; Brasell, 1990), e.g. when asked to draw a position or time graph of a moving ball, some university students from the USA (details not given) tried to sketch graphs which mirrored the shape of the track (McDermott *et al.*, 1987).

- **Understanding the meaning of the shape of the graph in relating variables.** Research has shown that students have problems describing relationships between variables. Students often do not understand the fundamental relationships in graphs, with "top-down" processing of graphs restricted to determining specific values (coordinates) of variables (Brasell, 1990). Padilla *et al.,* (1986) found that only 49% of Grade 7 to 12 students in their study could describe relationships between the variables. Berg and Phillips (1994) found that only 30% of the Grade 7 students, 24% of the Grade 9 students and 66% of the Grade 11 students in their study could correctly interpret all questions about a simple line graph on crop production of three crops.

- **The "graph-as-picture" misapplication.** More often than not students interpret graphs based on the appearance of the graph. In their study, Mokros and Tinker (1987) found that of the 125 Grade 7 and 8 children studied, only 13% scored correctly in the pre-test, and in the post-test 77% of the students scored correctly. Tairab and Khalaf Al-Naqbi (2004) claim that students rely on their perceptions rather than cognitive interpretation of what they see.

- **The "back-to-the-future" graph.** Some students can manage to pick up the notion that some variable cannot go backwards, but they usually fail to identify this variable as time. Mokros and Tinker (1987) found that 13 out of 40 students (33%) scored correctly at pre-testing and 23 of the 40 students (58%) scored correctly in the post-test.

- **Difficulties with kinematics graphs.** Most science students, especially in the biological sciences, usually struggle to interpret this type of graph. Of the 524 high school and college level students investigated by Beichner (1994), only 40% could interpret kinematics graphs convincingly. This could be because kinematics graphs are mainly used in physics.

Intensive practice is necessary to develop graph interpretation skills, e.g. Cave (1995) believes that students need to have as much experience as possible with a wide variety of graphs, and teachers need to teach students how to interpret graphs, not just create them. Only then will students have the skills necessary to decipher the graphical information presented to them. Furthermore, most students need to be taught how to interpret the relationships defined by a graph as well as how to develop conclusions about the relationships. Cave (1995) points out that recognizing types of curves, identifying patterns, describing relationships depicted by graphs, and extracting information about a relationship from a graph, are all skills that should be developed.

1.2.3 Lack of awareness of graphing problems

Perhaps one of the biggest problems with graphs is that "*students (and even many teachers) are not aware of their graphing deficiencies*" (Brasell, 1990: 81). Furthermore, she cites a study which showed that it is not only students who have problems, and that 30% of the articles investigated in leading scientific journals contained graphing errors.

1.2.4 Lack of ability to transfer skills taught in one subject to other subjects

Brasell (1990) points out that most formal instruction in graphing happens in mathematics, and that few students are automatically able to transfer these skills to other subjects like the sciences. "*Successful learning involves the ability to transfer understandings from one context to another"* (Millar *et al.,* 1994). Seemingly graphing and graphing skills as taught in mathematics differ considerably from graphs and graphing skills as taught in the sciences. In mathematics graphs are used to visualize mathematical formulae, and to show how manipulating the mathematical variables changes the attributes of the graph. In the sciences visualization of the relationships between content-related variables is important. Trends are described in terms of scientific phenomena, rather than by means of mathematical equations. In the natural sciences far more use is made of graphs involving continuous variables other than time or space (what Tufte, 1983, cited by Brasell, 1990, calls "relational graphs"). Tufte's study showed that 67% of graphs in standardised tests in the natural sciences used relational graphs, while only 41% of the maths graphs used this type of graph.

1.3 GRAPHING SKILLS AND DEVELOPMENTAL TRENDS

Several studies have shown that the ability to graph is related to logical reasoning (Berg & Phillips, 1994; Wavering, 1989). In an extensive study in the USA with a very representative sample (1,416 subjects from an urban/suburban area comprising 50% boys and 50% girls from grades 8 to 12, from high-ability, medium-ability, and low-ability groups, and also from both public and private schools), Berg and Smith (1994) found that students who lack logical thinking abilities have serious difficulties when attempting to interpret or construct graphs. This has important implications for educators who try to teach graphing skills. As the following discussion reveals, students may not all have reached a stage where they can reason logically. Teachers need to be aware of this so they can plan teaching strategies appropriate to the cognitive level of their learners. For an example, Ates & Stevens (2003), in their investigation to compare line-graphing skills of 45 Grade 10 students of different cognitive developmental levels from two advanced chemistry classes in a public high school in the USA, found that formal reasoning students scored higher than concrete reasoning students.

After examining the graphing ability of 625 students from two school districts in North Central Georgia in grades 7 to 12, and finding that seventh and eighth grade students were less successful in graphing than high school students, Padilla *et al.* (1986) recommended that graphing skills should be introduced in earlier grades and be properly emphasized. Howe and Jones (1993) believe that graphing skills are easily accessible to elementary-age children, but this depends on graphing skills being taught effectively. Bruner (1977: 33) writes *"......any subject can be taught effectively in some intellectually honest form to any child* *at any stage of development"*.

The ideas of Bloom, regarding hierarchies of cognitive skills, and the ideas of Piaget about stages of development, provide a framework which helps us understand developmental trends in graphing skills. According to Bloom, a hierarchy of cognitive skills can be identified, and learning takes place at different levels for different individuals, depending upon their cognitive structure (Falk, 1971). The levels are arranged in the following hierarchy, according to "Bloom's taxonomy", as explained by Falk (1971):

- Knowledge : The learner recalls specific facts or simply brings to mind the appropriate material. Knowledge can be rote-learned.
- Comprehension : The learner can translate, re-order or re-arrange learned material and to some extent extrapolate, thus demonstrating an **understanding** of the concepts.
- Application : The learner can apply concepts and generalizations previously learned to new, practical or unfamiliar situations.
- Analysis : The learner, when presented with an organized whole or structured situation, can break it down and identify its elements.
- Synthesis : The learner puts elements or parts together to form a whole, a new structure or pattern.
- Evaluation : The learner makes judgements about value and accuracy of presented materials against established criteria.

According to Bloom's taxonomy, a student should be able to **construct** graphs at the comprehension level and a student who can **interpret** graphs is operating at the application level (Falk, 1971). It is pertinent to note, however, that this seems to conflict with the research findings that graph construction is more difficult than interpretation. Falk (1971) goes on to explain that the cognitive skills of knowledge, comprehension and application are the foundation skills which are necessary for the development of the skills of analysis, synthesis and evaluation. This can be related to the science process skills (see section 1.1.4) where it was shown that in order to be able to construct and interpret graphs, students need to have integrated science process skills, and the basic process skills on which they are based, i.e. communicating and predicting are the basic process skills which underpin the development of the skills of controlling variables, defining operationally, interpreting data and experimenting, which are integrated science process skills. Furthermore, Brasell (1990: 22) believes that graph construction and interpretation are *"an important aspect of experimentation"*. These cognitive skills are hierarchical, and less successful learners are less likely to be able to cope with skills higher up on the taxonomy of skills.

It is interesting to link these ideas to those of Piaget. According to Mwamwenda (1989), Piaget enumerated four stages of cognitive development, viz.:-

- sensory-motor stage (0 - 2 years) - refers to the child's development of the concept of object permanence.
- pre-operational stage (2 - 7 years) - characterized by rapid acquisition of language by the child.
- concrete operational stage (7 - 10 years) - when the child is capable of using a logical process of reasoning on the basis of concrete evidence.

- formal operational stage (adolescence and adulthood) - characterized by the ability of the child to engage in a high level of thinking without basing it on concrete evidence. Learners at this stage can engage in abstract thinking tasks.

From the above, one can infer that learners at the formal operational stage (from 12 years onwards) should be capable of constructing and interpreting graphs, although research shows that many secondary school scholars have not mastered graphing skills (McDermott *et al.* 1987). Indeed, *"the results of graphing research provide clues that reflect a developmental aspect to growth in graph construction and interpretation abilities"* (Berg & Phillips, 1994:324).

The stage of formal operations as proposed by Piaget is the highest level of thinking attainable. According to Mwamwenda (1989), if students are to attain the stage of formal operations, it is essential that they be provided with a suitable learning environment.

Brasell (1990) identifies three hierarchical levels of competency in graphing, i.e. "naive" graphers, "novice" graphers and competent "expert" graphers;

- At the lowest level students do not even know the fundamentals of the functions and properties of graphs.
- At the next level students can perform very basic graphing tasks.
- The third level contains very few students. These people are able to "*access and use a set of rules, or algorithms*" (Brasell, 1990:81) and as they become more proficient they no longer do this consciously, but are able to interpret graphs automatically because these rules have become integrated into their mental frameworks in a way which allows them to apply them automatically.

Understanding the developmental levels outlined above helps educators to realise why some students may struggle with graphing. Graphing skills might not be considered important by certain teachers or stressed very heavily in certain grade levels. The naive graphers have either never been taught graphing skills, or are operating at a low cognitive level. This might suggest that if graphing skills are introduced in earlier grades the way in which they are taught is critically important. Graphs should not just be there in the curriculum, but should be cognitively available to students.

In addition to the problem that some learners may not yet have reached a stage of cognitive development where they can handle graphs, the lack of graphing skills could be attributed to a number of other reasons, e.g. maybe graphing skills were never specifically taught, or maybe they were taught but in such an abstract way that students did not understand. According to Beyer and Charlton (1986: 207),

> *"Too often what we assume to be teaching of these skills consists instead only of making students attempt to use these skills, however they can best execute them, to solve subject matter problems ... As a result, students usually fail to learn these skills."*

From the above argument one would expect students who come to university to be at a level where they can master graph construction and graph interpretation when taught properly

1.4 AIMS OF THE STUDY

Based on the perceived need for improved graphing skills at first-year university level, the ultimate goal of this study was to produce and evaluate a web-based computer programme to improve first-year university biology students' ability to construct and interpret graphs. Prior to designing and developing the package, however, it was important to **establish the nature and extent of graphing problems and what stakeholders perceive could be done to address the problems** (see Chapter 2), so as to develop a suitable instructional programme which responded directly to the problems. It is this situational and needs analysis which made up the research described in this report.

1.5 IMPORTANCE OF THE STUDY

Research has identified competency in graphing as being of central importance to the practice of a scientific discipline (Rogers, 1995; Bowen & Roth, 1998). This study focuses on graphing skills and the difficulties that students experience in graph construction and interpretation. Without graphing skills they will struggle to interpret specific scientific data, which is often presented as graphs. In addition, students need to be aware that the same information can be represented in a number of ways, such as verbal, tabular, and graphical formats. This awareness will help them to be more critical as they read the formal scientific literature, particularly the methods and the results sections (which are two of the most important components of any published research). According to Pechenik and Tashiro (1992), when researchers read the literature in their field, they spend most of their time scrutinizing the tables and graphs looking for answers to particular questions about the results of the study, thereby forming their own opinions about how the data should be interpreted.

Even more so, the man in the street needs to be taught how to interpret graphs which appear daily in newspapers, magazines and on TV, because such graphs contain valuable information on issues ranging from AIDS (rate of infection and mortalities) to financial matters (progress of stocks and shares, fluctuating currency values, etc.), so readers and viewers need to be able to interpret them. I believe that this study will be of value to teachers of graphs, not only in biology but also in other areas of science and even other subjects where graphical representations help learners to understand the subject material more fully.

1.6 CONCLUDING REMARKS

This chapter has looked at the importance of graphs and reviewed the literature on problems associated with graphing. The next chapter will discuss the methods that were used to achieve the aims of this study.

CHAPTER 2

RESEARCH METHODS AND DESIGN

The purpose of this chapter is two-fold:

- to describe the methods used for gathering data, backed up by literature to justify the use of these particular methods,
- to justify the selection of the particular instruments used in the study and to describe their development and how they were used.

The flowchart on the following page summarizes the design of the study. This started with the reading of previous studies on the subject and related aspects of the subject, as advised by Nisbet and Entwistle (1970). It was at this stage that the researcher specified the aims of the whole study. According to Cohen and Manion (1980), this may begin with the outlining of the theoretical basis of the study, its broad aims, and the practical value of the study. At this stage the researcher can formulate a hypothesis about the important factors in this area of study. Questions can also be designed to test the hypothesis. This stage is referred to by Nisbet and Entwistle (1970) as the "period of stress for the will-be researcher." They point out that a certain strength of personality is needed to survive this stage and to be able to tackle it thoroughly. The next step is to select or develop appropriate instruments to gather the data to answer the research questions. Most of this chapter is devoted to describing this process.

2.1 RESEARCH QUESTIONS

In this research, the researcher set out to find answers to the following questions:

1. What graphing skills do the biology teaching staff at the University of the Witwatersrand expect from students entering first-year biology?
2. What graphing skills do first-year biology teaching staff at the University of the Witwatersrand teach and how?
3. What graphing problems are experienced by first-year biology students at the University of the Witwatersrand?
4. What strategies do first-year biology teaching staff believe are needed to rectify graphing problems experienced by their students?

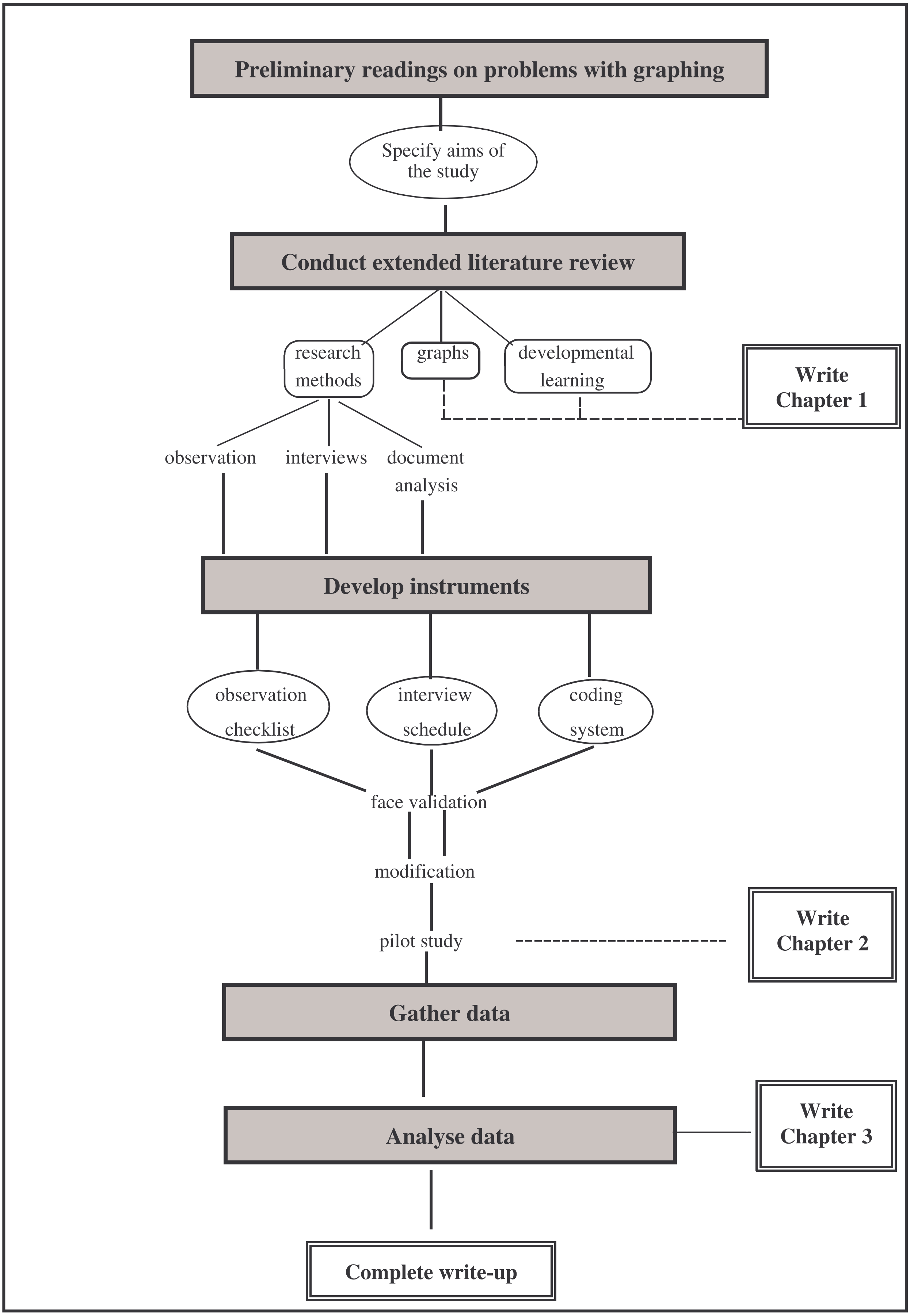


Figure 1: **Flow chart showing the design of the study**

2.2 RESEARCH PARADIGM

The term "paradigm" is popularly used in many contexts. In a research context, Reeves and Hedberg (2001) describe "paradigm" as a well-defined approach to doing research in a particular field. Different educational research paradigms each have associated beliefs regarding theories of knowledge and methods of gathering evidence. The quantitative paradigm was the dominant paradigm in educational research for many years. This paradigm carries positivist assumptions that human behaviour can be explained through objective facts, and researchers working within this paradigm tend to seek to verify generalisations, laws and causal relationships (Firestone, 1987; Peshkin, 1993). On the other hand, researchers working within the qualitative paradigm tend to seek to generate an understanding of the richness, complexity and ambiguity of a phenomenon (Firestone, 1987; Peshkin, 1993). The nub of the difference between the two paradigms is the starting point of the research inquiry. Quantitative researchers usually start with hypotheses, and try to verify or refute them, whereas with qualitative researchers the data comes first, and serves to generate hypotheses.

Typically, many researchers associate certain research methods with each paradigm, e.g. participant observation is often seen as a qualitative research method, whilst experimental methods are usually associated with the quantitative research paradigm. Curiously, qualitative researchers may sometimes use quantitative methods and vice versa. It is thus often misleading to use the terms "qualitative" and "quantitative" to describe research methods and techniques because educational researchers (who may be situated in a particular paradigm) employ a wide range of methods to gather quantitative and qualitative data. It is now widely accepted that the appropriateness of research paradigms depends on the nature of the research questions being asked. Each paradigm has certain strengths, but is also criticized due to inherent weaknesses. Some authors, such as Sanders (1986), Cohen and Manion (1987), and Johnson and Onwuegbuzie (2004) argue that the quantitative and the qualitative paradigms should be complementary.

Sometimes neither of the two most commonly used paradigms in research (the qualitative or the quantitative paradigms) is really suitable for use in **evaluation** studies. According to Reeves and Hedberg (2001), the quantitative paradigm basically relies on measuring variables and analyzing relationships among them using statistical techniques. It often aims to determine the comparative effectiveness or worth of one programme or product over another. On the other hand, the qualitative paradigm puts emphasis on the human being as the primary evaluation instrument (Reeves & Hedberg, 2001), and uses ethnographic methods of inquiry, especially human observations. The problem with this paradigm is that it aims at understanding contexts in their natural settings without any interference from the researcher (Fraenkel & Wallen, 1990).

A third paradigm was used for this research, the Paradigm of Choices, or what Reeves and Hedberg (2001) refer to as the "eclectic - mixed methods - pragmatic paradigm". This paradigm does not require researchers to start a study by deciding which paradigm they wish to use and stick to that. The methods of the study are determined by what information is needed and the best way to get it. This paradigm was used for this study because it deals with the practical problems that face educators and eliminates the tendency to value one research tool over another, which is a problem with the other two paradigms described by Reeves and Hedberg (2001).

2.3 RESEARCH APPROACH

The aim of this study was to establish the nature and extent of first-year university biology students' graphing problems. The long-term aim was to improve the graphing skills of our first-year students, using computer-aided instructional software. This requires a strong foundation of learning theory and what research showed about effective instructional design and the teaching of graphs. The short-term aim was to get to know the problems and what needed to be done so that the intervention developed was appropriate. It was therefore necessary to conduct a *situational*, as well as a *needs analysis*, prior to developing an intervention programme on the teaching of graphing skills. The intention was to establish whether the knowledge level on graphing skills was indeed a problem. The *situational analysis* was conducted to determine the nature and extent of the problem, and the *needs analysis* was undertaken in order to determine what needed to be done to solve the problem.

This study involved survey research. A survey is a research approach in which data are collected from part of a larger group (population), for the purpose of describing one or more characteristics of the whole group (Jaeger, 1988). According to Leedy (1989), the word *survey* means to look or to see over or beyond the casual glance or the superficial observation. Surveys

> "*gather data at a particular point in time with the intention of describing the nature of existing conditions, or identifying standards against which existing conditions can be compared, or determining the relationships that exist between specific events*"
>
> (Cohen *et al.*, 2001:169).

Surveys are used frequently in educational research to describe attitudes, beliefs, opinions, and other types of information. Bell (2001) points out that surveys aim at obtaining information that allows patterns to be detected and comparisons made. Fraenkel and Wallen (1990) identify three major characteristics of surveys:

1. Information is collected from a group of people in order to *describe* some aspects or characteristics (such as abilities, opinions, attitudes, beliefs, and/or knowledge) of the population of which that group is a part.

2. The main way in which the information is collected is through *asking questions*; the answers to these questions by the members of the group constitute the data of the study.

3. Information is collected from a *sample* rather than from every member of the population.

2.4 DATA-GATHERING STRATEGIES

2.4.1 Purpose of the data-gathering strategies

In order to provide answers to the research questions posed at the beginning of this chapter, three strategies were used to gather the data, i.e. interviews, observations and document analysis. For this study, interview schedules were used as the original instrument. In addition to interviews, observations and document analysis were used as supplementary strategies of collecting data to enrich the information collected by interviews, and to allow for triangulation of data (as a validity check).

2.4.2 Interviews

An interview can be defined as:

> *"A two-person conversation initiated by the interviewer for the specific purpose of obtaining research relevant information, and focussed by him on content specified by the research objectives of systematic description, prediction or explanation,"*
>
> (Cohen & Manion, 1980: 291).

Interviews are usually in one of three forms, i.e. structured, semi-structured, or unstructured. Structured interviews are when the questions are organised in advance, i.e. the wording and sequence of questions are predetermined and the interviewer cannot change the questions during the interview (Cohen & Manion, 1987). In unstructured interviews the interviewer has little control or a vague idea of the questions to be asked, and the interviewee has the freedom to say whatever comes to mind. The interviewer formulates or derives the questions as the interview progresses (Cohen & Manion, 1987). In semi-structured interviews the interviewer has a list of pre-prepared questions, but may deviate from the list and follow interesting trends that may arise during the interview. For this study, semi-structured interviews were used.

Interviews were selected as the most appropriate main instrument for the study, in spite of several drawbacks such as the fact that they are time-consuming to conduct and analyse, and that they require skilled interviewers to maximise their potential for information gathering. Interviews provide an excellent way to gather data from subjects, because they provide the interviewer with time to establish rapport and the opportunity to indicate a genuine interest in the respondent's answers, thus promoting co-operation (McMillan and Schumacher, 1993). They also allow for dialogue between interviewer and interviewee so that clarification and probing are possible. Semi-structured interviews were used since, as pointed out by Bell (1987), they ensure that pre-prepared questions do not go unanswered, yet are flexible enough to allow for probing if answers given are incomplete or need clarification.

Advantages of using interviews

For this study, data from the teaching staff could have been collected in two possible ways, i.e. interviews and questionnaires, but interviews were selected as the data-gathering instrument because of a number of benefits, discussed in this section. According to Fraenkel and Wallen (1990) the use of interviews is probably the most effective way there is to enlist the cooperation of the respondents in a survey. In a personal interview, the researcher (or trained assistants) conduct a face-to-face interview with the respondent. As a result, this method has many advantages over questionnaires, which will serve as a justification of why interviews were used for this particular study instead of a questionnaire:

- **They allow for gathering of more in-depth data:** Gay (1976) asserts that, when well conducted, interviews can produce in-depth data which is not possible to get at with questionnaires. This is due to the fact that in an interview the interviewer is present and can therefore "dig" deep into the respondent's mind so that in-depth information is obtained.
- **They are flexible:** In contrast to questionnaires, interviews are flexible and can allow the

interviewer to adapt the situation to each respondent.

- **They allow for rapport to be established:** Because an interview is a two-person interactive method of data-gathering, the interviewer can establish rapport and a trust relationship, and thus be able to obtain data that the respondent would not give in a questionnaire. This is probably due to the fact that the interviewer can explain and clarify both the purpose of the research and the individual questions (Gay, 1976; Hopkins, 1976), hence the interviewer can possibly get more accurate and honest information. Mouly (1970) adds that because of the establishment of rapport, the respondent is encouraged to give more complete and probably more valid answers than might be possible with a questionnaire.
- **They allow for probing:** Interviews provide the opportunity to secure additional information by asking additional questions when a respondent's answer is either unclear or off the mark (Jaeger, 1988), and this can help the interviewer to get reasons for particular responses (Gay, 1976). Interviews, with their probing ability, allow the interviewer to probe into attitudes and motives of which even the respondent may not be aware of (Gay, 1976). Interviews are able to help the respondents to clarify their thinking on a given point so as to give an accurate answer. For instance, if the respondents cannot remember, then the interviewer may structure the field for them perhaps by pointing out some event that may refresh the respondents' memory. This is not possible with questionnaires.
- **They allow for new directions to be explored:** Interviews, because of their flexibility, enable the researcher to pursue a given lead so as to gain insight into the problem and to obtain more adequate answers, and they can also lead to significant insights in unexpected directions. This can lead to by-products which were not anticipated in the original plan of the study but which might be of significance to the outcomes of the study.
- **They permit additional data-gathering by observation:** In addition, an interviewer who actually sees the person being interviewed can secure information through observation. By watching body language, an interviewer sometimes can tell whether a respondent understands the question being asked, is willing to respond, and has more to say if encouraged to do so.
- **They facilitate gathering of data difficult to express in writing:** According to Dyer (1979) interviews allow for examination of emotion-laden topics that are difficult to express in writing. In the case of respondents who are reluctant to take a stand, who are not clear on their position or who are reluctant to admit certain facts, with an interview it is possible to get below the surface of the *"cliché"* of such a person (Mouly, 1970).
- **They allow the researcher better control over data gathering procedures:** Unlike a questionnaire, which is out of the hands of the researcher the moment it is sent, interviews allows the investigator/researcher to remain in "command" throughout the entire investigative situation (Gay, 1976; Vockell, 1983).
- **They obtain better response rates:** With the interview, since the researcher personally "administers" the tool, a greater percentage of return is promoted, and this can increase the validity of the results. In the case of questionnaires a low percentage of return is possible due to the fact that the respondents might feel that they are not obliged to return their responses.

Limitations of interviews

Like any other tool, interviews have a variety of advantages and disadvantages. The following are some of the limitations of interviews which apply in the case of this study:

- **They are time consuming to conduct:** Interviews, being a one-to-one approach, are often more time consuming to conduct than other information-gathering processes, and this may get tedious for the respondent. It also means that the researcher can deal with only small numbers of subjects in a particular period of time, so samples are usually smaller than if questionnaires are used.
- **They do not provide an immediate written record of the data:** Time is needed to transcribe the interview responses, which are also not easy to analyze (Vockell, 1983).Thus, training is required to conduct good interviews.
- **Interviews tend to be less objective than other strategies:** In interviews it is difficult for the researcher to strike a balance between complete objectivity and trying to put the respondent at ease (Mouly, 1970) and this may affect the way respondents answer the questions. Interviewers can change the nature of the data, adding bias to the results with verbal and nonverbal reactions and with their choice of probes (Thompson, 1978). It is easy to accidentally influence answers by giving verbal and physical clues that suggest an answer or indicate the interviewer's own opinions.
- **They carry the risk of bias:** The presence of the interviewer may reduce respondents' spontaneity. The responses given may be biased and affected by respondent's reaction to the interviewer, either positively or negatively (Thompson, 1978). This means that the respondents are more likely to answer some questions in a way intended to please the interviewer, rather than truthfully. It is also harder to explore sensitive issues face-to-face than in a written questionnaire where people may feel more comfortable revealing sensitive material.
- **Interviews are highly dependent on the mood of the interviewee:** The success of the interview may depend on the respondent's willingness to give accurate information, depending on the atmosphere where interviews are taking place, which can affect the validity of the information provided.

The main disadvantages of interviews which were pertinent in this study was the potential for subjectivity and bias. It requires a skilled and experienced interviewer to minimize these problems. Good interviews depend on the researcher being experienced and well-trained. The researcher's inexperience could result in the interviewee being uncomfortable, which could affect what they say. Furthermore, an inexperienced researcher may ask leading questions or perceive interviewees' responses inaccurately. These disadvantages can threaten the validity of both the interview data and the interpretation of the data. Measures that were taken to counter these threats are discussed as development of the interview schedule is described, later in the chapter.

Validity and reliability of interviews

Educational research should have an impact on the improvement of educational practice (Sanders, 1993). She points out that this will only be possible if the results of such research are valid and reliable. The methodological issues in interviewing are serious and involve both issues of validity (how appropriate is the measuring instrument to the task at hand? - Fraenkel & Wallen, 1990), and reliability (how consistent are the results of repeated applications with the chosen measuring instrument? - Cohen *et al.*, 2001). Open-ended questioning requires interviewers to know when to probe and how to formulate follow-up questions on the fly.

Interviewers must always remember that it is not the obligation of the interviewee to be objective and to tell the truth, hence the instrument may not always measure what it is supposed to. Interviewers have a purpose in requesting an interview but may ignore the reality that interviewees have a purpose in the interview too: they have something they want to say (which may not always be what the instrument is designed to measure). Consciously or unconsciously, they have thought about what they want to say in the period between the request and the actual interview. They are talking about what they know and, as such, justifying what they do. For the interviewer the skill factor is knowing when to probe and when to continue on with the sequence of questions on the interview protocol. Even allowing for some elasticity in the time taken up by the interview, there is a very real limit to how many probes can be asked. The same interviewer might not probe at the same point or with the same question in two otherwise similar interviews, the results of which might render the instrument not 100% reliable.

The value of flexibility of the interviewer to explore unanticipated answers should not be underestimated. At the same time, it is important to develop some consistency in the way probes are used. Although each subject is unique, many of the problems interviewers encounter in interviewing are common ones that interviewers confront over and over again. Systematic approaches to those problems will enhance interviewers' confidence in the quality of the data. One problem, according to Tuckman (1978), is that the validity of interviews will be limited by the extent to which the questions might influence respondents to show themselves in a good light, i.e. to be unduly helpful by attempting to anticipate what researchers want to hear or find out. Also, the extent to which the question might be asking for information about respondents that they are not certain about could have a bearing on the validity of interviews as they may give inaccurate answers that may influence the gathered data.

For this study necessary measures taken to improve the validity and reliability of the interviews are discussed in the following section.

Designing and using the interviews

The purpose of the interviews was to establish the extent to which the teaching staff currently require their students to use graphing skills in their first-year biology courses, the specific graphing skills they expect their students to have mastered, problems they believe are exhibited by their first-year students (with reference to graphing skills), and the nature and extent of current teaching of such skills in first-year courses, as well as what they felt needed to be done regarding the teaching.

Preparation stage

The first step in designing the interviews was the preparation stage. First an extensive literature review on planning and implementing interviews was conducted. This was done while the researcher was attending a course on "Research Methods and Design in Science Education" during which several class exercises were carried out in which interviewing techniques were dealt with extensively. Details are included here to illustrate steps which were taken to improve the quality of the research in this study.

- The class was divided into small groups. Each member of the group was asked to read a number of different articles to extract advice and suggestions on how to plan, design and use interviews.
- In class, all the points from various group members were collected and listed on strips of paper. These were then sorted and grouped together into different categories relevant to planning, designing and using interviews.
- A mind map was then constructed on a big chart, by pasting all the collected points from the different groups for each process in a logical order, i.e. for planning, designing and using an interview.
- These then served as guidelines for the interviews which each student had to conduct. Some of the major guidelines used to design the interviews are summarised in Table 4.

Table 4. Advice on designing and using interviews

Advice	Reason	Reference
1) Preparing for the interview.		
Review literature on interview design.	To find out how other researchers who did similar studies designed and carried out their interviews. This may give the researcher some more ideas on how to design the interviews for the present study.	Nisbet and Entwistle (1970).
Decide on the population and the sampling procedure.	To ensure that the sample is that of people who possess the desired information.	Gay (1981).
Decide on the recording method & equipment.	Some instruments may not always be good for a particular interview, e.g. there might be fear of tape recording.	Thompson (1978).
2) Designing the schedule.		
Questions should be short, simple and straightforward.	This is necessary in order to avoid ambiguity, and so the interviewee does not lose track of what is being asked.	Trochim (1999).
Avoid double questions & leading questions.	To ensure that the responses will give you the information you are seeking.	Rummel (1964).
3) Conducting the interview		
Questions should be asked as they are written.	Alteration of the wording of questions should be done during the rehearsal of the interview, not during the interview, so as not to lose focus of the interview.	Trochim (1999).
Use eye contact and a confident manner.	To set the tone of the interview and help the respondent to get comfortable.	Rummel (1964).
Use verbal probing, and “silent probes” if appropriate.	Pausing might suggest to the respondent that the interviewer is waiting for what the respondent will say next.	Trochim (1999).
Interview responses should be recorded immediately.	Some information may be lost if some time is allowed to elapse between interview and recording.	Galfo (1975).
Use a tape recorder if possible.	Tape recording of the interview session will produce the most complete and accurate record of what was said.	Hitchcock & Hughes (1989)
An interview should end on a positive note, e.g., thanking the respondent.	Even if the respondent was troublesome or uninformative, it is still important to be polite and thank him for his time.	Gowin and Novak (1994).

Every student was then required to formulate interview questions on a relevant topic, and then prepare an interview schedule for those questions based on the advice from the group activities. Each individual then interviewed one of their colleagues for a five-minute interview, which was video-recorded. During these simulated interview sessions the other members of the class watched. The interviews were then played back to the class and each student was required to do a self-critique of the whole process, as well as getting feedback from the other members of the group and from an expert in "research methods". Comments were then made during a feedback discussion, including both the positive and negative points on the evaluation forms that were provided. The feedback included highlights of the good points that came out of the interviewing process, and gave each member an opportunity to improve on the weak points on the interviewing techniques. Each student had a chance to watch the others practising their interviewing skills, hence getting more ideas on how to conduct good interviews.

Developing the interview schedule

The next step was drawing up an interview schedule, i.e. questions that were going to be asked in the interview as well as the reasons for asking those questions. The reasons were added in order to make me as the researcher, metacognitically aware of why I was doing things, thus increasing the chances of me meeting my research objectives, and ensuring my research questions were answered. This step therefore involved translating research objectives into research questions which would be able to get the information that I need to obtain from the study, as recommended by Cohen *et al.* (2001). There were ten main questions designed, followed by a number of probing questions. The probes were designed to prepare for situations in which the respondents might not understand the main question, i.e., to clarify and get them talking again, and to get the respondents to explain their answers in more depth.

Face validating the interview schedule

The interview questions were face-validated by two science educators to check on the following:

- that the questions were designed to meet the research aims.
- that the questions were as simple and as straightforward as possible, so the interviewees could understand them.
- that the questions were not ambiguously worded.
- that there were no leading questions which might suggest answers to the interviewees.
- that the way questions were worded was likely to elicit the required information.

Piloting the interview

Before the actual study, a pilot study was conducted so as to practice and improve on the interviewing techniques. Details are provided on page 32. The main aim of the pilot study was to identify weaknesses in the interviews, such as where more probing could have been done. All this was done to help the researcher improve on the interviewing techniques. Furthermore, the pilot study was conducted so as to carry out the transcriptions and coding to check that the coding system developed was feasible.

A pilot study is a “test-run” study on a similar group of subjects, in order to try out an instrument so that potential problems can be detected and rectified before the main study. The interview schedule in this study was piloted for the following reasons:

- to check that the wording of the questions was clear and unambiguous,
- to identify if the probing questions were adequate,
- to find out how long an interview session would take, so interviewees in the main study could put aside sufficient time,
- for the interviewer to practice his interviewing technique,
- and to ensure that the planned data analysis was feasible and effective.

For the pilot interview, one biology lecturer who taught graphing to the first-year biology course for medics was used, as Rummel (1964) explains that it is important that the pilot study is carried out on persons who are not in the interviewing sample but from whom the same desired information can be obtained. Because the sample of lecturers teaching graphing skills was so small, it was not possible to pilot it with more than one lecturer. The interview took approximately fifteen minutes. The interview was audio-taped, with the permission of the respondent. Hitchcock and Hughes (1989: 94) state that “*tape recording of the interview session will produce the most complete record of what is being said*”, and also allows for accuracy of the data to be checked. The following points were considered when asking the questions:

- The questions were asked exactly as they were written so as not to change the meaning and therefore possibly not get the required information. The pilot study gave an opportunity to discover if there were any changes necessary.
- When response were not clear, probing was done for explanation and clarification. Trochim (1999) advises that the most effective way to encourage someone to elaborate is to pause and wait, and this he refers to as the “silent probe”. Pausing might suggest to the respondent that the interviewer is waiting for what the respondent will say next.
- At no stage whatsoever was the interviewee interrupted or assisted in answering the questions, as this could “lead” the respondent, hence affecting the answer given.

The responses from the pilot interview were then transcribed and the transcriptions reviewed by an “expert” on interviews, firstly to check their accuracy, but more importantly for comments on the interview technique and how it could be improved. Cohen *et al.* (2001: 281) point out that transcribing “*is a crucial step, for there is a potential massive data loss and distortion and the reduction of complexity*” if transcription is not accurately done. As expected, a lot was gained from the “expert’s” comments, as there were a couple of important points raised on how to improve the interview technique. For example, the expert suggested an increase in the number of probing questions. It was also suggested that notes be made during the interview, whereby facial expressions and body movements would be recorded where relevant, for example, when the interviewee supplied evidence (question papers or practical manual) to back up their comments, which was not clear from the tape. The interview schedule and techniques were modified according to the feedback obtained during the pilot study. The final interview schedule developed is shown in Table 5.

Table 5. Interview schedule for first-year biology lecturers

Main question	Possible probe questions	Reasons for asking
What first-year course do you teach?		
In that course do you expect your students to use graphing skills?	If "yes", then ask: – Please explain what you expect them to do with graphs.	To determine skills lecturers require students to use.
What graphing skills do you expect students to have when they enter first-year?	If they don't seem to understand, then ask: – What do you expect them to be able to do with graphs when they arrive in first-year from school? If they dry up, then ask: – From where do you expect them to get graphing skills? – Do you expect them to be able to read and interpret graphs? – Do you expect them to be able to construct graphs?	To determine the lecturers' expectations of the students when they come to university.
Which types of graphs do you expect your students to use in your course?	If they don't seem to understand, then ask: – Do you expect them to use line graphs for instance? – Which other types of graphs do you expect them to use other than line graphs?	To establish the types of graphs used in the first-year biology course.
In the first-year classes you have taught, do students seem to have graphing problems?	If "yes", then ask: – Can you describe the graphing problems they have that you have picked up in your teaching? If they dry up, then ask: – Do they have problems in constructing graphs? – Do they have problems in interpreting graphs?	To establish nature and extent of graphing problems of first-year biology students at the University of the Witwatersrand.
Do you think first-year biology students should be taught graphing skills if they seem to lack them?	If "yes", then ask: – How should the skills be taught? – By whom should the skills be taught? If "no", then ask: – How do you think they will be able to acquire the skills?	To determine whether, if such skills are needed and missing, it is the lecturers' responsibility to teach them at university level.
What do you do, if anything, about teaching these skills?	If they dry up, then ask: – Do you specifically teach graphing skills? – Are there any special measures that you undertake to improve the students' graphing skills?	To establish what, if anything, is being done to teach these skills to first-year students, if they are needed but lacking.
Do you use any particular strategy to teach graphing skills?	If "yes", then ask: – What strategies do you use to teach graph construction? – What strategies do you use to teach graph interpretation?	To establish if the lecturer believes graphing skills are important enough to necessitate emphasis on students acquiring those skills.
Do you assess graphing skills in your course?	If "yes", then ask: – When do you assess the skills? – How do you assess the skills?	To find out if the lecturer believes graphing skills warrant any assessment.
Do you have test or exam papers for me to look at the questions?	If "yes", then ask: – Do the questions on graphs count significantly in the tests or exams?	To determine the importance of graphing skills in the course.

Main study

The final step, after all the necessary alterations were made and the interview schedule was finalized, involved conducting the interviews for the main study. All lecturers involved in *using* or *teaching* graphing skills to first-year biology students at the university (n = 5), as well as four "teaching assistants" involved in demonstrating during first-year practicals, were interviewed using the same interview schedule. For reasons described in Chapter 3, this sample will be referred to as the "teaching staff".

Thompson (1978) advises that in order to ensure the comfort of the respondent, a setting with as little distraction as possible must be chosen. In this study the participants were interviewed in the comfort of their own offices or work labs at times that were convenient to them. The interviews for the study were audio-taped, with the permission of the interviewees, in order to obtain an accurate and complete record of the responses, and to facilitate analysis of the data. The whole interview process lasted for two weeks, and the interviews were conducted under the same considerations outlined in the previous section on the pilot study.

The interview schedule started with an opening statement to the interviewee which gave a brief description of what the study was all about and what was expected of the respondents. The introductory statement was as follows:

> *"I am conducting a study for my MSc about the development and evaluation of a web-based computer programme on graphing skills for first-year university biology students. I am hoping that you could help me by responding to a few questions. I understand that you might be teaching at different levels, so I would like you to keep details of your answer at the first-year level. Also, if my questions are not clear, I would like you to tell me. You are free to elaborate on any matter that I might have left out, and you feel is important and relevant. I have also provided you with a pen and paper in case you want to write down some thoughts or ideas".*

The interviews were transcribed verbatim. A coding and categorisation system for the responses was developed. This was a rigorous process that went through a series of modifications, including checking of coding by an expert (research methods lecturer) to check on validity and reliability issues. The data analysis process is described in section 2.5 (page 37).

2.4.3 Non-participant observation

For purposes of triangulation to check the validity of the findings, non-participant observation was used during a three-hour practical involving graphing, during which the researcher observed 29 students over two sessions (15 students in one session and 14 students in another) in one "bay" of the lab, using a checklist and field notes to record information about how the students were coping, and any possible problems they were experiencing.

Observing a graphing skills practical *in situ* was suited to gathering information about graphing problems as they were experienced by the students in their natural setting. The context in which the graphing problems occurred was observed to gain some understanding of the demands relating to graphing skills from the students' perspective, and to witness first-hand the graphing problems as they arose. According to McMillan and Schumacher (1993), using observational methods can be advantageous in that rather than relying on the subjects' responses to questions or statements, this method relies on the researcher's perception and recording of the observations. Thus the observational data is not restricted by the subjects' self-report bias or by what the subjects can accurately recall.

Before the observation procedure, the researcher attended a pre-laboratory tutorial. This session was given by the lecturer co-ordinating the practical on graphing skills, and its purpose was to brief the students on the practical. During this session:

- The students were reminded that they know the difference between dependent and independent variables.
- The students were told that the biggest problem commonly encountered when working with graphs is scaling, and were given tips on how to deal with fractions when determining the scale of a graph.
- When asked by the lecturer what difficulties they might have with different types of graphs, the majority of the students said that they had problems with log graphs. It was then explained to them that log graph paper works in cycles, i.e. a series of compressions each to the power of 10. It was explained that log paper exaggerates the smaller numbers and compresses the bigger numbers, and always starts with big units that progressively become smaller.
- When asked about the other types of graphs by the lecturer, the students claimed that they did not have problems with bar graphs, histograms or pie charts.

One medical biology class, "Introduction to Medical Science" (Biol 142) was selected for observation during a practical session on graphing skills. As outlined in the introduction section of the practical manual used for the practical (BIOL 142 Introduction to Medical Science: Resource and Practical Manual), the practical is aimed at "*alerting the students to the different concepts associated with graphing and affords the students some experience at this skill*". In the laboratory, the students were seated at 16 lab benches comprising 8 "bays". Each bay seated 15 students, eight at one lab bench and seven at the other, with students at the two benches in a bay sitting back-to-back, leaving a walking passage between them. In each practical there was one teaching assistant for each bay, a chief teaching assistant overseeing the whole lab, and the coordinating lecturer who was supervising the whole proceeding. One bay was arbitrarily selected for observation for the purposes of this research.

The researcher attended three practical sessions, as the practicals were run on three different days in order to accommodate all students in the very large class. Each practical lasted for three hours. With the first group of students (referred to as the "pilot group") the researcher was observing problems in order to develop a checklist, which was then used to systematically observe problems with the second and third groups.

The *"continuous observation recording procedure"* described by McMillan and Schumacher (1993) was used to record brief descriptions on an observation schedule of events during the pilot practical. Using this method, descriptions of events which I decided were important were written in chronological order during the observation session. From these notes, I sat down with an expert (research methods lecturer) to construct an observation schedule (see Table 6). When the observation schedule was constructed, answers from the interviews and literature were used to determine broad categories of the type of events to record.

Table 6: Checklist used during the observation of a practical session

Skill	Problem
Construction	Not knowing that the title is written below the graph.
	Assigning variables to axes, i.e. not knowing which variable to put on the x-axis and which variable to put on the y-axis.
	Choosing a suitable scale for each axis, i.e. not knowing how to use the whole graph paper sheet.
	Inability to draw line of best fit when provided with a piece of paper with several points scattered on it.
	Not knowing when and how to use log graph paper, e.g. log by linear grid or log by log grid.
Interpretation	Inability to determine the x and y co-ordinates of a point.
	Extrapolating, i.e. inability to predict what might happen outside the range of what has been measured.
	Describing relationships between variables, i.e. which variable depends on the other.

At the start of each practical the researcher was introduced to the students as a researcher interested in teaching and learning about graphing skills, for the purpose of later developing a computer-based learning resource programme on this topic for the students. Practicals were observed by mingling and talking briefly with staff and students as they worked. Students occasionally asked the researcher questions about their work, possibly assuming that he was one of the teaching staff, but the researcher politely avoided engaging in the activities. The non-participant observation method of standing aloof from the learning activities was used, as opposed to participant observation where the researcher engages in activities being investigated (Cohen & Manion, 1987).

As mentioned earlier, the first practical session was aimed at fine-tuning the checklist which was originally developed with information gathered from literature review and scrutinised with the help of an expert (research methods lecturer). This checklist was then used to gather data during the remaining two practical sessions comprising of 15 and 14 students respectively. During the two practical sessions, the researcher walked around and observed students as they worked, tallying down the type of problem on the checklist each time a student asked a question from teaching assistants. At the end of each of the two practical sessions, the researcher asked each student from the research sample about which problems they had encountered during the practical and recorded the responses on the checklist. The information gathered is presented in the next chapter.

2.4.4 Document analysis

Having conducted interviews with the staff and teaching assistants involved in teaching graphs, and having observed students in action in a graphing practical, it was decided to do a survey on performance results from examination papers in order to triangulate the information gathered from interviews and observations, using a larger sample so that a more accurate measure of the extent of graphing problems could be established. This phase of the research was really *ex post facto* research (where data was not collected during the research but the data analysed already existed). The method used for this study was document analysis. Documents, according to Fraenkel and Wallen (1990: 413), refer to "*any kind of information that exists in some type of written or printed form*". In general, historical source material can be grouped into four basic categories: documents, numerical records, oral statements and records, and relics. In this case the documents were examination papers of past students, i.e. their answers to examination papers.

In this study, students' answers for all graphing-related questions in the mid-year examination papers of two first-year classes were subjected to item analysis, to identify the nature and extent of graphing problems exhibited. The classes involved were the medics class BIOL142 (n=478) and a College of Science class BIOL123 (n=65). It is relevant to note that the College of Science students had followed a course in which the development of skills is strongly emphasized, and where all necessary academic skills (including graphing) are specifically taught. This is not typical of tertiary level courses, as most tertiary educators assume that students will have been taught graphing skills at school level (Brasell, 1990).

In the first group of students, because of the class size (n = 478), the examination was in the form of multiple-choice questions. The answers had been computer marked, and an analysis of the correct and incorrect answers was provided by the computer. In the second group of students, the analysis of correct and incorrect answers from open-ended questions was conducted by the researcher from the students' answer books for the exams. Both question papers are given in Appendix 3. Only the questions that tested graphing skills were selected and analyzed from the question papers, the results of which will be presented in the next chapter.

2.5 DATA ANALYSIS

The main purpose of data analysis is to make sense of the collected data.

2.5.1 Interviews

As discussed in an earlier section, each interview was transcribed immediately after it was conducted. This was done in order to pick up problems in the interview technique, and to identify possible difficulties in the analysis process, so that these could be corrected before the next interview.

Developing a coding system

Coding, as defined by Kerlinger (quoted by Cohen and Manion, 1986: 306), is the "*translation of question responses and respondents information to specific categories for the purpose of analysis.*" On the interview transcripts, all the quotes which seemed to contain information which would answer the research questions were highlighted. This was done to identify which data to come back to for analysis. Trends coming out of the highlighted answers were identified by the researcher, and these were listed as sub-categories to be used for coding. Codes for the categories were then created (*e.g.* **PC** for problems with construction, **TG** for type of graph). This process was then checked and approved, after a rigorous process of modification, by an independent "expert". These codes were used as a form of shorthand to facilitate the analysis process, but were not used for reporting the results. The coding system developed is shown in Tables 7 - 13, which represent the coding schedule for categories of the interviewees' responses.

Table 7. Lecturers' expectations from the students on their graphing skills

Sub-category	Explanation	Code
When they enter first-year.	They don't need any graphing skills.	EF1
	To know what a graph is and what it represents.	EF2
	Should be able to interpret graphs.	EF3
	Should be able to construct graphs.	EF4
During the first-year course.	Select the appropriate type of graph for data provided.	ED1
	Be able to construct graph results.	ED2
	Be able to see different trends in the data they collected.	ED3
	Must be able to see a graph and explicitly interpret what it means, e.g. that what is on the y-axis is influenced by what is on the x-axis.	ED4

Table 8. Types of graphs students need to use

Graph type	Code
Line graphs.	TG1
Pie charts.	TG2
Histograms.	TG3
Bar graphs.	TG4
Log graphs.	TG5
Scatter-graphs.	TG6
Regressions.	TG7

Table 9. Problems students experience

Sub-category	Explanation	Code
Constructing.	Cannot tell which type of graph to use for a given data set, e.g. difference between continuous and discontinuous data.	PC1
	Identifying which is the dependent and independent variable.	PC2
	Identifying which variable should be plotted on which axis.	PC3
	Battle to work out an appropriate scale for the graph.	PC4
	Carelessness, i.e. not plotting points accurately.	PC5
	Don't know what "extrapolating" means, so cannot figure out when to use a straight line or a curve.	PC6
	Often forget to label axes.	PC7
	Sometimes leave out the units.	PC8
	Headings aren't very descriptive.	PC9
Interpreting.	Not able to read the coordinates, and therefore don't know what the axes represent.	PI1
	Get confused when there are two vertical axes.	PI2
	Battle with the quantitative description of what the graph is showing, e.g. from day 1 to day 6 there was a 10% increase in whatever.	PI3
	Battle to explain what causes changes in the graph in terms of the theory, i.e. the content of the graph.	PI4
	Do not have problems with interpreting graphs.	PI5

Table 10. How graphing skills should be taught

Explanation	Code
By explicitly lecturing about important aspects to the students.	HT1
By giving them practice in using the skills, i.e. paper based exercises.	HT2
By providing opportunities for students to apply graphing skills in further new situations.	HT3
By providing feedback for students who exhibit problems.	HT4
By allowing students to use computers to generate graphs. The problem here is they often don't understand what it is they are doing because the computer does some of the work, e.g. calibrating the axes.	HT5
By making better use of audio-visual aids like overhead transparencies.	HT6
A combination of a lecture outlining the skills, with some practice exercises to follow up.	HT7
Should be taught on a practical level.	HT8

Table 11. When graphing skills should be taught

Sub-category	Explanation	Code
In practicals.	A whole practical devoted to graphing skills.	WT1
In tutorials.	Various aspects of graphing must be explained, e.g. dependent and independent variables.	WT2
In lectures whenever needed.	Give explanations during the lecture in an *ad hoc* basis whenever a new principle is needed.	WT3
In a specific lecture.	Integrate the skills in the lectures.	WT4
In self-study projects.	Have to do little experiments in which they collect data and are expected to draw their own graphs and interpret them.	WT5

Table 12. Who should teach the skills

Sub-category	Explanation	Code
School.	Basic knowledge of graphs.	WSB
University.	Tutors / Lab staff.	WU1
	Lecturers.	WU2
	Students themselves.	WU3
	Early on in the first-year, a specific time should be scheduled for teaching graphing skills.	WU4
	People from the education field should design special practicals or tutorials.	WU5
Both school and university.	School should give the knowledge and the university reinforces.	WSU

Table 13. Teaching and assessing the skills

Sub-category	Explanation	Code
How graphing skills are currently being taught.	Skills are not taught currently.	CT1
	Ask which axes there are.	CT2
	Ask the parameters for each axis.	CT3
	Ask the meaning of the graph.	CT4
	Ask how the graph is constructed.	CT5
Do you assess the skills?	Yes.	SA1
	No.	SA2
When do you assess the skills	In practicals.	WA1
	In tests.	WA2
	In exams.	WA3
How do you assess the skills?	Ask them to produce a graph.	HA1
	Ask them to label the x and y axes.	HA2
	Ask them to show the units of measurement.	HA3

The allocation of codes on the interview transcripts was done twice - once by the researcher and once by an independent “expert”. Codes were then compared, and where different codes had been used these were discussed and an agreement reached.

2.5.2 Document analysis

This section describes the way in which the analysis of the question papers was done. Two mid-year examination papers were analyzed, one from the “Introduction to Medical Science” course (Biol 142, n = 478), and the other from the “College of Science” (Biol 123, n = 65). Only the questions that tested specific graphing skills were selected from the question papers. Tables 14 & 15 in the next pages reflect essential basic knowledge of graphing skills (based on literature, and validated by two experts in the area of science education) upon which the analysis of the question papers was based. It was important to develop a categorisation system which would help to determine the type of graphing skills the students were expected to have, as well as the specific skill that was tested by each question. This was a very rigorous process that went through several stages of refining.

The first examination paper used a multiple-choice format and Table 14 (on the following page) specifies the skills and knowledge assessed by each question. In some cases (questions 13, 14 & 15), as the graph was an “unseen” one, it could be interpreted without requiring specific content-based knowledge. Apart from the graphing **construction** skill required, the questions tested graphing **interpretation** skills. Although content-based answers were required, content knowledge was not a pre-requisite for successfully answering these questions. The questions were of a data-response type where unseen data is used, and what is being assessed is the ability to use a skill.

How this was used to code the data and how the coding was checked

- A printout was obtained from the subject lecturer with the marks (in percentage) from the multiple-choice questions that involved graphing.
- Tables were developed to determine knowledge and/or skills tested by each question, together with correct and incorrect responses obtained by the students (see chapter3), and these were checked and verified by an expert.

Table 15 (on page 43) summarizes the graphing skills required in the questions which tested graphing in the second class (comprising College of Science students who had specifically been taught graphing skills). Some of the questions involved performance tasks which largely tested students’ ability to **apply** the rules of graphing to actually *construct* a graph, while others tested their ability to *interpret* the graph they had constructed.

Table 14: Criteria used for analysing question paper for the medics exam 'BIOL 142'

Ques. No.	Whether knowledge and/or skills are tested	Graphing skill	Specific skill tested
1	Knowledge of subject content and graphing skills.	Interpretation	Ability to interpret trends in a graph in light of knowledge of both content and graphing skills. Subskills required to answer this question are: • To establish what is being represented on each axis. • To look at the units and how they quantify the data. • To look at the shape of the graph to see what is happening to the dependent variable. • To link what they (students) have seen in the graph and their content knowledge to interpret the graph.
11	Knowledge of an appropriate graph schema.	Interpretation	Ability to recognise the following types of graph paper: • linear by log cycle graph paper • log cycle by log cycle graph paper, and to identify the number of cycles shown on the page.
12	Ability to apply knowledge.	Construction	• Ability to identify the independent variable from data given in a table. • Knowledge of which variable (dependent or independent) goes on which axis. • Ability to identify how many log cycles would be needed to plot a graph from tabulated data provided including small numbers expressed as a power of 10.
13	Recognition, i.e. visual image automatically activates elements in long-term memory.	Construction	• Ability to identify the dependent variable from data given in a table. • Ability to identify discontinuous (discrete) data.
14	Designing the graph to enhance visual perception.	Construction	Ability to calculate angles for a pie chart from data provided.
15	Recognition, i.e. visual image automatically activates elements in long-term memory.	Construction	• Ability to identify the dependent and independent variable from a table of data provided. • Ability to identify continuous and discontinuous data from a table of data. • Ability to select the appropriate type of graph to plot from any given data. • Ability to select the appropriate axes on a graph with more than one y-axis.
19	Knowledge of subject content & knowledge of graphs.	Interpretation	Because the question was based on a graph already plotted by the students in the tutorials but not shown in the paper, it tested only knowledge and not skills. • Knowledge and understanding of the subject content, i.e. enzyme/substrate relations. • Understanding of how the graph (encountered previously in a practical) was plotted, why it was plotted in this way, and what the graph represented. • Ability to identify the independent variable in the graph. • Knowledge of the shape of a rectangular hyperbola and the trends it represents.

Table 15. Criteria used for analysing question paper for the College of Science exam 'BIOL 123'

Ques. No.	Whether knowledge and/or skills are tested	Graphing skill	Specific skill tested
5a	Knowledge / understanding of the subject content & graphing.	Interpretation	Ability to read annotations on a graph and to give a qualitative description of what the graph is showing. This includes: • Ability to establish what is being represented on each axis. • Ability to explain what is happening to the dependent variable by looking at the shape of the curve.
5b	Knowledge of subject content & graphing.	Interpretation	• Ability to give logical meaning by applying the appropriate grammar provided by the graph schema in long-term memory. • Ability to translate visual information in the graph into a conceptual message.
7a	Knowledge of subject content & graphing.	Construction	• Ability to plot points on a graph from data provided in tabular form and to link the points. • Ability to identify the dependent and independent variable from data provided in tabular form. • Ability to select correct axis to plot each of the two variables. • Ability to choose the correct type of graph for the data provided. • Ability to work out an appropriate scale for the graph. • Ability to correctly label the axes of a graph they have constructed (including the units of measurement). • Ability to provide a suitable title for a graph.
7b	Knowledge of subject content & graphic cognition.	Interpretation	• Ability to attach meaning to a graph they have constructed according to a set of rules or grammar. • Ability to convert visual image into meaningful information. • Ability to give a qualitative description of what the graph is showing.
7f	Knowledge of subject content & graphing.	Construction	• Ability to correctly annotate a graph (or provide a legend/key). • Ability to predict changes in trends when a variable is manipulated.
8	Knowledge of subject content & graphing.	Interpretation	• Understanding of the variables or substantive concepts being graphed. • Ability to use the algorithms or grammar for decoding information in the graph. • Ability to explain what causes changes in trends shown in the graph in terms of content knowledge.

How this was used to code the data and how the coding was checked

  - A mark allocation schedule was obtained from the lecturer who had set the question paper.
  - A table was set up whereby for each answer book the marks obtained by the student for each point were recorded.
- The common incorrect claims (misconceptions) made by the students were noted and coded.

- A final table for each question was produced with the sum of responses of the students in percentages (see Chapter 3).
- The coding was checked by an expert and the subject lecturer.

2.6 CONCLUDING REMARKS

This chapter reviewed the methods used to obtain the information to answer the four research questions which guided the study. In the next chapter the data obtained will be presented and discussed.

CHAPTER 3

RESULTS AND DISCUSSION

The purpose of this chapter is to present and discuss the results obtained from the study. The chapter aims at answering the main research questions of this study. To achieve this aim, the results and discussion will be structured around the four main research questions, and the results from the situational and needs analysis will be presented separately.

3.1 SITUATIONAL ANALYSIS

As mentioned in the earlier chapters, this study is intended to establish the nature and extent of problems being experienced by the first-year university biology students investigated, what is currently being done to teach graphing skills at the university in question, and whether the problem is extensive and serious enough to warrant developing supplementary teaching materials to teach graphing skills, with the long-term goal being to improve the graphing skills of the first-year students at the university.

Research question 1. **What graphing skills do lecturers at the University of the Witwatersrand expect from students entering first year biology?**

3.1.1 Graphing skills expected from first-year biology students

Nine staff members involved in teaching first-years were interviewed to ascertain what they expected the first-year biology students to be able to do, in terms of graphing. The following tables reflect the frequency counts from the responses of the teaching staff (lecturers and teaching assistants, based on the interviews) of the teaching staff's expectations. In the middle column of the table the five lecturers are referred to as L1 to L5 and the four teaching assistants are identified as T1 to T4.

Perhaps it is imperative at this point to describe the lecturers' role, as well as what each lecturer teaches. Lecturers design courses, teach classes, and set all assessment tasks. In addition to the pilot interviewee, two of the lecturers teach the medics, i.e. L1 and L4. The medics courses seem to be at a more advanced level than the mainstream biology courses. Two of the lecturers teach a mainstream course called

"Introductory Life Sciences", i.e. L2 and L3. One lecturer (L5) teaches the "College of Science" course, which specifically focuses on and teaches a range of process skills and academic skills needed to improve the chances of academic success. It is important to note that the teaching assistants are post-graduate students who assist students during the practicals by answering their questions. Although not staff members, they are also included under "teaching staff" in this report because of the teaching role they perform during practical sessions. All four of the teaching assistants taught the medics, one also taught the main stream Introductory Life Science course (T2), and one also taught the College of Science course (T4). There is therefore some overlap with some teaching assistants, i.e. T2 is involved with both the medics and ILS, whereas T4 assists with the medics and the College of Science.

On entering the course

The teaching staff were asked about their expectations of first-year students at two different times, i.e. on entering university, and what they will need during the course of the year.

Table 16. Teaching staff's expectations of students' graphing skills when they arrive at university

Explanation	Respondents	Frequency (n=9)
Students don't need any graphing skills.	L1, L5.	2
Students should know what a graph is and what it represents.	L4, T1.	2
Students should be able to interpret graphs.	L2, L3, L4, T1, T2.	5
Students should be able to construct graphs.	L2, L4, L5, T1, T2, T3, T4.	7

Two of the five lecturers did not require students to have graphing skills **when they enter** university.

> *"Oh, they don't need any graphing skills".* (Lecturer #1)
>
> *"We don't exp... we, it would be nice if they had, but we don't expect them to have any. So we assume that we are actually starting from the beginning, in terms of graphing".* (Lecturer #5)

Other answers illustrated that students were expected to possess some basic graphing skills when they come to university. Five of the nine teaching staff expected students to be able to interpret graphs, as explained by one teaching assistant, and explained in more detail by one of the lecturers:

> *"I expect them to basically know what a graph is, and to basically understand what a graph is supposed to represent".* (Teaching Assistant #1)
>
> *"I expect, eh first-year students, having got through matric, to be able to interpret a graph. In other words to eh, visualize how a particular variable, eh, changes with*

> *respect to another.... But I expect them to see, eh ... to be able to interpret what the graph is telling them in terms of both of the axes, both the vertical and the horizontal axes. I would expect them to be able to read off exactly what changes are taking place, eh .... looking at both of those axes and the scales".* (Lecturer #2),

However, as pointed out by Tamir and Amir (1987), being able to interpret a graph is not necessarily a reflection of the ability to construct a graph (Chapter 1, section 1.1.4). Seven of the nine staff members expect students to be able to construct graphs. One lecturer explained that

> *".....they have a self study project that they do, where they have to do a little experiment on plants and then they have data so they are required to draw up their own graphs and interpret those".* (Lecturer #5).

The following response from one staff member, when asked if he expected the students to be able to construct graphs, explains expectations in more detail (emphasis is mine).

> *"... yes indeed.... the practical level, ehm, I eh .... they collect data, they tabulate the data and although .... frequently I don't have the time during the practical to allow them to actually draw all the graphs, I actually allow .... I insist they do the first one .... any subsequent graphs I expect them to do at home and I make it clear to them that this material is indeed examinable.* ***So the onus is on them to understand the data, to graph it accurately****, ... with my assistance of course I give them all the parame..., the ...the ...the, the data points for the graphing and they tabulate those data points and I expect them to actually draw the graph. I generally point out that we have a dependent and an independent variable".* (Lecturer #2)

It does appear that the teaching assistants focus more on the need to be able to do graph construction when entering university than the lecturers, as all four of the teaching assistants expected the students to be able to construct graphs whereas only three of the five lecturers stated this as a requirement for students entering the course.

During the course

Although the researcher expected the teaching staff's expectations of skills when entering the course, and later in the course, to be different, the responses suggest that the teaching staff did not seem to be drawing a clear distinction between their expectations of students on entering university and during the course of the year.

Table 17. Teaching staff's expectations of students' graphing skills during the course of the year

Explanation	Respondents	Frequency (n=9)
Students should be able to select the appropriate type of graph for the data provided.	L5, T2.	2
Students should be able to see different trends in the data they collected, i.e. must be able to see a graph and explicitly interpret what it means, e.g. that what is on the y-axis is influenced by what is on the x-axis. (Interpret graphs).	L1, L3, L5, T1.	4
Students should be able to graph results from simple experiments. (Construct graphs).	L1, L2, L5, T1, T2, T3.	6

From Table 17, it can be seen that one additional skill is expected during the course of the year. Two teaching staff (one lecturer and one teaching assistant) expected the students to be able to select the appropriate type of graph for provided data, as illustrated below,

> *"So we might give them, ehm, a table of data and they have to use that data to actually draw up the appropriate type of graph".* (Lecturer #5).

Two thirds of the teaching staff believed that first-year students should at least be able to plot results from simple experiments, as illustrated by the following interview extracts,

> *"Well I would think that they should be able to read, uhm ..... say tables of results and transfer those results onto a very simple graph".* (Teaching Assistant #2).
>
> *"Just basically to represent data that they would have collected in the lab, eh ..... on experiments that were done, like respiratory experiments ..... just to plot, ... to see different trends in their data they collected".* (Teaching Assistant #1).
>
> *It's just very simple graphs where, they conduct simple experiments, and then they have to graph their results".* (Teaching Assistant #3).

Table 18. Types of graphs teaching staff expect students to be able to use (n = 9)

Graph type	Respondents	Frequency
Line graphs.	L1, L2, L3, L4, L5, T1, T2, T3, T4.	9
Histograms.	L1, L4, L5, T1, T3, T4.	6
Bar graphs.	L5, T1, T2, T3, T4.	5
Pie charts.	L1, L5, T1, T3, T4.	5
Log graphs.	L4, T1.	2
Scatter-graphs.	L1, L3.	2
Regressions.	L1, L3.	2

The teaching staff did little more in the interviews than just list the types of graphs they expected students to be able to use, and did not elaborate further. All the teaching staff expected the students to be able to use line graphs, but fewer staff seemed to emphasize the need to work with histograms, bar graphs or pie charts, which are common ways of presenting data in the media and in scientific articles. Only two of the teaching staff said students need the skill to use log graphs, scatter-graphs and regressions, which are not commonly used in the media or at school level. It is interesting to note that the teaching staff who required students to use log graphs were both involved in teaching the medics, where one of the practicals requires students to use this type of graph. The two teaching staff who needed the skill to use scatter-graphs were the same ones who needed the skill to use regressions, as shown below,

> *"....mainly scatter-graphs and, uhm, occasionally maybe a regression...."* (Lecturer #1).
>
> *"Okay, we have things like regressions, line graphs eh, that sort of thing, things that will be covered in a spreadsheet under the title of scatter-plots".* (Lecturer #3)

3.1.2 What graphing skills are taught and how?

Having determined which skills were expected from first year students, it was necessary to determine the skills that were actually taught, if any, and the methods and strategies used to teach the skills so as to establish the current situation and to plan possible solutions, i.e. whether the present situation warrants remedial measures. This section answers the following research question.

Research question 2. **What graphing skills do first-year biology lecturers at the University of the Witwatersrand teach and how?**

All the teaching assistants confirmed that they do not teach graphing skills. Two of them explained further:

> "*....answer their questions .... then mark their lab reports ...."* (Teaching Assistant #1),
>
> *"..... when you're marking their practicals, to mark quite carefully and to put comments on where they're wrong and why they're wrong. But for the rest, I don't really, you know, do much of it at all".* (Teaching Assistant #2).

Some lecturers stated in no uncertain terms that they do teach the skills, or the skills are definitely taught, e.g. the pilot interviewee, who was a medics lecturer, claimed that

> *"We, we, in this, we teach, **specifically teach,** graphing skills".*

This was confirmed by two lecturers in the main study who mentioned that students were specifically taught graphing skills at the beginning of their course, even if not by them *per se,*

> *" .....students have a prac devoted **specifically to learning** graphing skills".* (Lecturer #1)

" .....we have specific tutorials, that are set aside and focus on graphing". (Lecturer #5)

Interestingly, these two lecturers (L1 & L5) were the same ones who said they do not require students to have graphing skills when they enter first-year (Table 16). This implies that the reason these skills are taught at first-year is because they do not expect them to have these skills when they come to university.

Lecturer #1 said the practical was devoted to learning graphing skills, but from what I observed during this practical session students were only given graphing problems to solve, with occasional assistance from the teaching assistants, and no formal teaching was done in the practical. As discussed in Chapter 2 even the pre-laboratory tutorial had no structured formal teaching. The lecturer asked the students what problems they had with graphing, and when they said they had none, he said that students often struggled with log graphs, and went on to give them tips on how to tackle log graphs. Possibly by giving students graphing problems during a practical the lecturer assumes to have taught the skills because often what teachers believe is the **teaching** of skills consists only of getting students to **use** these skills, as pointed out by Beyer and Charlton (1986), (see Chapter 1, section 1.3). This possibility is supported by the following comments from the pilot interview, where the lecturer states that they **use** the skills (rather than that they are taught the skills), and then **presumes** that their graphing skills improve.

> *".... we have the practical which we use, and then the follow-up usage of graphs in later practicals. .... this practical that I run, ... presumably they have better graphing skills at the end of it than at the start of it ...."* (Pilot interview)

The problem could be that some lecturers do not seem to understand what "teaching a skill" involves. Some lecturers stated that they do not have any particular strategy to teach graphing skills, but do it by "*integrating it into the course*" (Lecturer #3), or only when the need arises, e.g. *" I teach when I see that they don't understand"*. (Lecturer #4).

From the above responses the lecturers' emphasis on **teaching** graphing skills was not clear, hence the researcher felt it necessary to determine the importance placed on graphing skills by establishing whether the skills were formally assessed or not.

Table 19. Indication of which teaching staff claimed to assess graphing skills (n = 9)

Category	Respondents	Frequency
Yes.	L1, L2, L3, L4, L5, T1, T3, T4.	8
No.	T2.	1

Table 19 shows that graphing skills are assessed, with only one teaching assistant stating that she did not assess the skills. My understanding was that Teaching Assistants do not set tests, but they mark lab reports, as shown in the earlier quotes. This implies that even teaching assistants are, to some extent, involved in assessment. One particular lecturer, who teaches in the College of Science where graphing skills are specifically taught, commented that,

> *"You know we're quite particular in terms of our, our, you know when we mark a graph, if the students have had to, say in a test draw up a graph. We will allocate marks for, eh the accuracy of the plotting of the points and also the labeling of the axes, you know. Have they given what the axis is and the unit of, of that? Have they given the graph an appropriate title or legend? Is it written below the graph? So we're quite particular in terms of eh, ... you know the, the things that we look for, and that we award marks for. And sometimes they are a bit careless in not actually labeling the axes, and that sort of thing".* (Lecturer #5).

This comment by Lecturer #5 reflects the approach used by the College of Science (which is a two-year bridging course equivalent to the first year of the mainstream Biology course aimed at improving the chances of success of "at-risk" students, and the role of formative assessment in teaching plays an important part).

Table 20. When the teaching staff claim they assess graphing skills (n = 9)

Category	Respondents	Frequency
In practicals.	L5, T1, T3, T4.	4
In tests.	L1, L2, L3, L5.	4
In exams.	L1, L2, L3, L4, L5.	5

As expected, Table 20 shows that the teaching staff indeed assess the skills in their respective areas of operation. Teaching assistants assess the skills in practicals and the lecturers assess the skills in tests (four out of five lecturers) and in exams (all the lecturers). This has far-reaching implications in that it means lecturers tend to do summative assessment (at the end of the teaching and learning session), which is judgmental in its role rather than playing a role in the learning process as does formative assessment. Summative assessment does not usually help the students because it does not allow time to review strengths and weaknesses as it comes at the end of the teaching/learning process, and students seldom get feedback.. Students stand a better chance of learning from the formative assessment they get from the teaching assistants. Formative assessment has more benefits for the students in that they get early specific feedback throughout the process of learning. This continuous feedback helps them to timeously identify their strengths and weaknesses, thus giving them a chance for remedial action to improve their learning.

3.1.3 Graphing problems experienced by first-year biology students

To answer the next research question, the researcher attended a practical session of the medics class and also analyzed two question papers (one from the medics class and the other from the College of Science class), in addition to the interviews, in order to establish the extent of the students' graphing problems.

Research question 3. **What graphing problems are experienced by first year biology students at the University of the Witwatersrand?**

Six of the teaching staff (L3, L4, L5, T1, T2, T3), in addition to the "pilot" interviewee, said that their students have problems with graphing. A wide array of problems experienced by students were put forward by the teaching staff, based on their experiences with first-year students. As shown in Table 21, these problems could be clustered into two broad areas, interpreting and constructing graphs.

Table 21. Problems with graphing skills, as identified by the teaching staff (n = 9)

Category	Explanation	Frequency	
Interpreting graphs.	Difficulties in reading the coordinates, and not knowing what the axes represent.	L4, T3.	2
	Getting confused when there are two vertical axes.	L4.	1
	Battling with the quantitative description of what the graph is showing, e.g. from day 1 to day 6 there was a 10% increase in *"x"*.	L3, L5, T2, T3.	4
	Difficulties in explaining what causes changes in the graph in terms of the theory, i.e. the content of the graph.	L3, L5.	2
Constructing graphs.	Difficulties deciding which type of graph to use for a given data set, e.g. for continuous and discontinuous data.	T2, T4.	2
	Identifying which is the dependent and independent variable, or deciding which variable should be plotted on which axis.	L5, T1, T2, T4.	4
	Difficulties working out an appropriate scale for the axes.	L5, T1.	2
	Carelessness, i.e. not plotting points accurately.	L5, T3.	2
	Don't know what "extrapolating" means, so cannot figure out when to use a straight line or a curve.	L4.	1

The next table, Table 22, shows students' problems, identified from the question paper analysis of the medics examination. Because of the large class the exam was designed as a multiple-choice exam and marked by computer. Seven of the questions in the exam involved graphing and these were analysed to determine what knowledge or skill was tested by each question. This analysis was validated by a science education lecturer. The skills required to correctly answer the questions are presented in Table 22 on the next page.

Table 22. The nature and extent of problems medical students had with graphing skills tested in seven multiple-choice questions from the Biol 142 examination (n=478)

	Question no.	Knowledge and / or skills tested in each question	Percentage of students: No answer	Wrong answer	With a problem
Interpretation	1	Tested the ability to interpret trends in a graph in light of knowledge and graphing skills. Skills assessed were the ability to ▸ establish what is being represented on each axis ▸ understand the units and how they quantify data ▸ interpret the shape of the graph and what happens to the dependent variable ▸ link graph changes to content knowledge	3.4%	5.4%	**9%**
Interpretation	11	Ability to recognize types of graph paper (linear by log cycle graph paper, and log cycle by log cycle graph paper) and to identify the number of cycles shown on the page	8.2%	9.6%	**18%**
Interpretation	19	Because this was based on a graph constructed in a practical it demanded only recall of content and graphing knowledge ▸ Knowledge and understanding of the subject content ▸ Understanding of how the graph (encountered previously) was plotted, why it was plotted in this way, and what it represented ▸ Ability to identify the independent variable on the graph ▸ Knowledge of the shape of a rectangular hyperbola and the trends it represents.	22.8%	35.8%	**58%**
Construction	12	▸ Ability to identify the independent variable from data given in a table. ▸ Ability to identify which variable (dependent or independent) goes on which axis ▸ Ability to identify how many log cycles would be needed to plot a graph from tabulated data including small numbers expressed as a power of 10	10%	46.1%	**56%**
Construction	13	▸ Ability to identify the dependent variable from data given in a table. ▸ Ability to identify discontinuous (discrete) data	10.5%	16.9%	**27%**
Construction	14	▸ Ability to calculate angles for a pie chart from data provided	18.6%	7.3%	**26%**
Construction	15	▸ Ability to identify the dependent and independent variables from tabulated data ▸ Ability to identify continuous and discontinuous data from a table of data ▸ Ability to select the correct type of graph to plot from the given data ▸ Ability to select the appropriate axes on a graph with more than one y-axis	22.4%	57.5%	**80%**

In Table 22 there are three results columns presented in percentages. The first column shows the percentages of students who did not answer the question. The second column shows the percentages of students who did answer the question but gave an incorrect answer. The last column is the sum of the two and represents the total percentage of the students who appeared to have a graphing problem.

Table 23 shows students' problems from a medics class as observed by the researcher during three practical sessions. In column four of the results n = 29 for the main study, because two groups were observed on different days (n=14 and n=15). The fifth column shows the total students observed during the pilot study and the main study. At the end of the practical, as the students were leaving, the researcher asked them what problems they experienced during the practical, and this shown in the last column. It should be noted that the results in this last column may not be an accurate representation of the extent of the students' problems in that the students may have been in a hurry to leave, or they did not want to admit (for some other reason) that they had problems.

Table 23. Students problems with graphing as observed by the researcher during practicals (n = 43)

Skill	Problem	Pilot study	Main study	Total	Students admitting they had problems
		(n=14)	(n=29)	(n=43)	(n=29)
Interpretation	Determining coordinates.	1	0	1	0
	Describing relationships.	1	2	3	1
	Interrelating graphs.	3	2	5	0
Construction	Plotting points.	0	0	0	0
	Assigning variables to axes.	6	0	6	0
	Scaling axes.	7	8	15	9
	Using line of best fit.	4	7	11	0
	Extrapolating.	1	1	2	0
	Using a log graph paper.	4	6	10	3
	Constructing a pie chart using a formula.	1	0	1	1
	Determining which graph paper to use.	1	1	2	0

The discussion and synthesis of the students' problems that follows is based on the data from the three different sources, i.e. teaching staff interviews, observations and question paper analysis. This was done for the purposes of triangulation.

Problems with graph interpretation

Although Table 21 shows a wide variety of problems both in constructing and in interpreting graphs, not all the problems which emerged from the observations of the students during practicals had been predicted by the teaching staff. The following discussion reports on problems identified by one or more of the three sources.

- ***Determining coordinates***

One lecturer and one teaching assistant had said that determining coordinates was one of the problems experienced by the students,

> *"In the beginning they forget to read, for example the, uhm, coordinates, to see what does the x-axis represent and what does the y-axis represent"* (Lecturer #4).

In the observation of the practical session, one student had a problem with coordinates during the pilot observation, although none of the students admitted at the end of the practical that they had a problem (Table 23). The fact that only one student was seen to have the problem could have been because students did not have problems or the researcher could have been side-tracked by other observations and failed to pick up this particular problem. No results were obtained from the question paper analysis.

- ***Describing relationships***

Brasell (1990) found that extracting essential information from a given graph, and explaining trends shown in the graph in terms of content knowledge, was a problem for many students in the USA, a problem similar to what was revealed during the staff interviews (L3, L5, T2, T3), as illustrated by the following quotes,

> *"they tend to often battle with the quantitative description because they just look at the graph and they say "Oh the line goes up and the line comes down", rather than actually saying, you know from day one to day six there was a ten percent increase in whatever, that's ultimately what you're trying to get them to do"*. (Lecturer #5).
>
> *"They seem to have an inability to interpret what the graph is telling them. So, for example, if you've got a pair of axes with, say temperature on the x-axis and metabolic rate on the y-axis, and you draw a line there and say 'what does that graph tell you?' And the simple interpretation in this positive relationship here would be that as temperature increases the metabolic rate goes up ... they can't tell me that. They, ... they have got no clue how to interpret that graph at all"*. (Lecturer #3).

In addition to that, half the teaching assistants (i.e. 2) believed that students battle with the quantitative description of what the graph is showing, e.g.

> *"Well, specifically, I mean, you know if they constructed a graph, say of oxygen consumption, and then you give them a whole set of different figures and ask them to read off that graph that they've drawn, some of them do battle"*. (Teaching Assistant #2).

The class observations confirmed that this problem existed. Three students exhibited this problem during the practical, although only one student admitted at the end of the practical to having had the problem. This is shown in Table 23 as the only interpretation problem that any student said they experienced.

The students' lack of ability to establish what is being represented on each axis was also one of the problems identified when the multiple-choice questions from the medics exam paper (Biol 142) was analyzed (see Table 22, question 1), but only 9% of the students had a problem with this question and probably, therefore, had this problem.

The lack of this skill from some students is supported by evidence from the analysis of the other question paper (from the College of Science - Biol 123), in which most students lacked the ability to explain what was happening in the situation being graphed (Question 5a, Table 24) and (Table 25, Question 8a).

Research has shown that students have problems understanding the meaning of the shape of the graph in describing how one variable relates to another (Padilla *et al.,* 1986; Brasell, 1990). Tables 24 and 25 illustrate some students' lack of the ability to explain what is happening to the dependent variable by looking at the shape of the curve.

Table 24. Number of students with correct answers for Question 5 in the College of Science exam (n=65)

	Correct responses required.	**Total**	**%**
Question 5a	Chlorophyll a & b remain constant between 60% & 70% from Jan to Feb.	13	20
	There is a dramatic drop in chlorophyll a & b starting just before March.	17	26
	The decline continues until May before the leaves are shed at 0%.	12	18
	The yellow carotenoid and the red anthocyanin remain constant between 50% & 60% from Jan to March.	9	14
	Just before April the yellow carotenoid and the red anthocyanin gradually decline at a rate above the chlorophyll a & b pigments.	18	28
	The decline continues steadily until around mid May when the concentration is about 10% before the leaves are shed.	12	18
Question 5b	Between April and May the leaves will be red and yellow before they are shed.	49	75
	This is due to the fact that the percentage of yellow carotenoid and the red anthocyanin is higher than that of chlorophyll a & b.	36	55

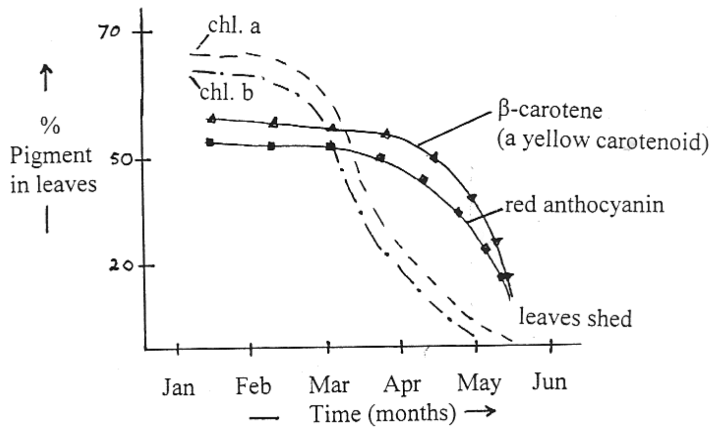


Figure 2. Changes in pigment content in the leaves of a deciduous tree, the Maple tree, over the period January to June in Johannesburg, South Africa.

(a) Explain the observed changes in the pigments in the leaves of the Maple tree over the time period January to June. (3 marks)

(b) What colour will the leaves be in the period April to May before they are shed? Explain your answer. (3 marks)

Figure 2: Graph-related components of Question 5

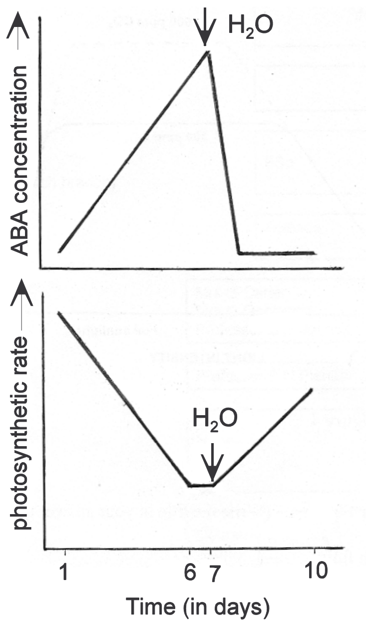
In Question 5a students needed to give six points in order to obtain full marks for the question. Each point needed the student to be able to do four tasks: read the legend, establish what is represented on each axis, read x and y values, and explain changes in the slope of the curve (see Figure 2). For two answers (of the six) just over a quarter of the students (26% and 28% respectively) were correct (i.e. could do the four graphing tasks required). For a further three points (of the six) only about a fifth of the students (20%, 18%, 18%) gave correct responses. For the sixth point only 14% of the students were correct. This suggests serious lack of mastery of the skills. At least three quarters of the students could not give each of the six points, suggesting they were struggling with one or more of the four graphing tasks needed to interpret the graph. Question 5b yielded better results. For this question two points were required to answer the question satisfactorily. The first point required the students to be able to translate visual information in the graph into a conceptual message, and 75% of the students could do it. The second point required students to be able to give logical meaning of their interpretation of the graph, and 55% of the students gave the correct response.

Table 25 shows that some students showed very poor understanding of the variables or substantive concepts graphed in Question 8a.

Table 25. Number of students with correct answers for Question 8a in the Biol 123 exam (n = 65)

Correct responses required	Total	%
ABA concentration increased steadily in the first six days.	51	78
Photosynthetic rate decreased steadily for six days.	48	74
Photosynthetic rate remained constant from day 6 to day 7.	9	14
ABA conc. dropped dramatically when water was added.	47	72
The dramatic drop in ABA concentration lasted for one day.	3	5
After one day the ABA conc. stayed the same.	10	15
The ABA conc. then remained constant until the end of the experiment.	3	5
Photosynthetic rate increased steadily when water was added.	50	77
The increase in photosynthetic rate continued until the end of the experiment.	5	8

In a set of experiments with grapevines, both the photosynthetic rate and the ABA concentrations were measured for a 10 day period. The plants were not watered for the first six days, but on the seventh day of the experiment the plants were given water. The results of the experiment are shown below.



Results of the grapevine experiment

a) Provide a comprehensive explanation of the results obtained from this set of experiments.
(8 marks)

Figure 3: Graph-related components of Question 8

The table illustrates the lack of ability of some students to explain what causes changes in trends shown in the graph in terms of content knowledge, and the ability to use the algorithms or grammar of graphing for decoding information in the graph (see Figure 3). For this question, nine points were required to answer the question completely correctly. All points tested students' understanding of the variables depicted on the graph and their ability to explain what causes changes in trends shown in the graph in terms of content knowledge. About three quarters of the students gave four of the nine points correctly (78%, 74%, 72%, 77%). In a further three answers, only about a fifth of the students provided the points correctly, and only 5% of the students correctly explained the last two points. Seemingly, students were able to understand a steady increase or decrease in a variable and could see when there is a change even though they were unable to explain what caused the change.

- ***Confusion with two vertical axes***

  Other specific skills that seem to be lacking included the ability to select the appropriate axes on a graph with more than one y-axis. One lecturer identified this, during the interviews, as a problem

  > *".... another problem is when they have two y-axes and one x-axis. They forget to read one, so they don't understand what is happening in the graph"* (Lecturer #4).

  This is corroborated by evidence from question paper analysis (Question 15, Table 22) which 80% of the students got wrong. One of the skills needed to answer this question was the ability to select the appropriate axes on a graph with more than one y-axis. This problem was not seen during the class observation. Brasell (1990, 74) points out that "*although graphs are powerful for two-dimensional data, they become increasingly more difficult to use effectively as the number of data dimensions (variables) expands*".

Although Bloom's taxonomy suggests that graph interpretation is more complicated than graph construction, some of the teaching staff did not share the same view. Two teaching assistants felt that students did not have problems with interpreting graphs.

> *"I haven't really seen problems with interpreting graphs. They seem to able to do that".* (Teaching Assistant #1),
>
> *"They generally don't, because most of the interpretation they do is off line graphs and they just draw the lines and they can read straight off, but the interpretation doesn't seem to be a problem."*(Teaching Assistant #4).

Certainly the research by Tairab & Khalaf Al-Naqbi (2004), in their study of 94 Grade 10 science students, found that construction problems were more serious than interpretation ones.

Problems with graph construction

From the pilot study of the observation of a practical session, as observed by the researcher (see Table 23), it appeared that graph construction posed more problems for the students than interpreting graphs. A similar trend was noted in the main study.

- ***Assigning variables to axes***

  The most evident problem experienced by the students in graph construction, according to the teaching assistants (3 out of 4), and one lecturer (see Table 21), was deciding which variable should be plotted on which axis.

  > *"......they battle with that ...they often get the axes the wrong way around"*. (Teaching Assistant #1).
  >
  > *"They battle, some of them, to know what should go on the x-axis and what should go on the y-axis"*. (Teaching Assistant #2).
  >
  > *"They don't know what to put on what axis. .... Some of them do, some understand straight away, but some really battle and don't understand and don't know what they are doing, even what a dependent and independent variable is .... what to graph, on which axis""*. (Teaching Assistant #4).
  >
  > *"The sorts of problems they have are things like identifying which variable should be plotted on which axis. In other words if you give them a set of data they often have problems deciding which is the independent variable and which is the dependent variable"*.(Lecturer #5).

  Of course there is always the possibility that the teaching assistants (who are post-graduates, and therefore still students themselves, and relatively recently undergraduates) may be basing their perceptions of problems experienced on their own experiences.

  In the observation of a practical session, six students were seen to have problems with assigning variables to axes during the pilot study (Table 23). But the problem was not picked up later on in the main study and no student admitted at the end of the practical to having had this problem. This raises questions about the reliability of observations of large groups as a way to gather data. Most of the teaching assistants felt strongly about this problem (and these are the people who deal with the students as they are graphing in practicals, so they may be more aware of problems than the lecturers) and yet the problem was not observed during the two practicals observed during the main study. Furthermore, the only lecturer who mentioned this problem happens to teach in the College of Science where teaching of skills takes precedence, and where the lecturers are working more closely with the students and are more likely to see the problems. Results from the medics BIOL142 question paper analysis (Table 22) also illustrated students' lack of ability to identify the independent variable (see Questions 12, 15) either from data given in a table or in a graph (56%, 80% respectively could not do it). Results from the College of Science BIOL123 exam also showed that students (9% of them) were unable to put the dependent and independent variables on the correct axes (Table 26).

- ***Scaling axes***

The problem of scaling axes was identified during the interview sessions by one lecturer and one teaching assistant, as illustrated in the following interview extracts.

> *"But sometimes they also battle to work out an appropriate scale for the graph. Ehm, you know they kind of don't plan ahead, or think ahead in terms of .... particularly drawing up the, the, the..., vertical axis. You know, they either have a scale that is very expanded, or a scale that is too contracted".* (Lecturer #5),

> *"Ehm, they often battle to determine the scale and what they need to do, eh, so, sometimes if the scale ranges from ... from 5 to 100, then they don't know how to plot the 5 to 100, you know, and they don't know what to do with the zero, whether they should have a zero at the bottom of the y-axis or the x-axis, ... they don't know that you can have broken graphs".* (Teaching Assistant #1).

This was substantiated by evidence from the class observations where the number of students who had problems with scaling axes was the highest of all the problems identified (total of fifteen students) Furthermore, nine students said, at the end of the practical, that they had experienced this problem. Question paper analysis for the College of Science examination (Table 26) revealed that some students were unable to choose a suitable scale for Question 7 in which they had to construct a graph (see Figure 4 on the next page). Students struggled to scale both the x and the y axes (31% and 38% respectively could not do it).

Table 26. Students' lack of mastery of various graphing skills for Question 7 of the College of Science exam (n = 65)

Question	Correct responses required		No. of students not able to do it	
Question 7a	Provided a suitable title		6	9%
	X axis	Chose a suitable scale	20	31%
		Labeled the axis appropriately	5	8%
	Y axis	Chose a suitable scale	25	38%
		Labeled the axis appropriately	14	22%
		Indicated the units of measurement	55	85%
	Put the dependent and independent variables on the correct axes.		6	9%
	Linked the values with a suitable line		16	25%
Question 7b	Able to read x-axis value (pH 6.6) at optimum rate of reaction (from y-axis).		25	38%
	Able to identify that the reaction rate above and below optimum is less.		21	32%
Question 7f	Line correctly inserted *below* the original line.		26	40%
	Line clearly labeled.		32	49%

In an investigation of the effect of pH on the activity of the enzyme amylase, barley seeds were soaked in water and allowed to germinate. The germinating barley seeds were crushed in distilled water, and the liquid was filtered to obtain an extract of the enzyme amylase. 5 ml of this extract and 5 ml of a starch solution were then mixed and incubated in a water bath at 40 °C. At exactly 15 second intervals, one drop of the mixture was added to a drop of iodine on a white tile. When the drop of the mixture stopped turning black in the presence of the iodine solution, it was assumed that the reaction had been completed. The time for this to occur was recorded. This was also carried out in a number of buffered solutions at various pHs.

The results of the experiment investigating the effect of pH on enzyme activity are presented in Table 1 below.

Table 1. The effect of pH on the reaction time of amylase on starch at 40 °C.

pH	Time for reaction to be completed (min)	Reciprocal of time (min^{-1})
4.5	7.5	0.13
5.0	6.0	0.17
6.0	4.5	0.22
6.6	3.0	0.33
7.2	4.0	0.25
7.5	5.5	0.18
8.0	7.0	0.14

(a) Using the results presented in Table 1; plot a graph of the rate of reaction catalysed by amylase at different pH values. (8 marks)

(b) Explain the shape of the graph you have plotted. (4 marks)

(f) On the graph that you have plotted, use another line (dotted/dashed and clearly labelled) to sketch the graph of results expected if the same experiment was carried out at 30 °C. (3 marks)

Figure 4: Graph-related components of Question 7

Figure 4, which shows the actual examination question, is shown on the following page.

- ***Deciding which type of graph to use***

Deciding on the type of graph to use when presented with data was identified as a problem by some of the teaching assistants, e.g.

> *"They also have problems with telling continuous data, that would possibly go on a line graph, from discontinuous data that would go either on a bar graph or on a histogram or something like that".* (Teaching Assistant #2).

> *" .... and they don't know what kind of graph to draw when. So they'll try to draw ... a line graph when they should be drawing a bar graph or histogram."* (Teaching Assistant #4).

The problem was not picked up by the researcher during class observation, probably because the medics mainly used log graphs in that practical, and the students were specifically told when to use the pie chart. Specific skills that seem to be lacking (see Table 22) included the ability to identify continuous and discontinuous data from a table of data (Question 15), as pointed out by Teaching Assistant #2 above, and the ability to select the appropriate type of graph to plot from any given data. This supports findings by Brasell (1990) in her study in the USA that selecting the appropriate type of graph to plot from any given data, i.e. identifying continuous and discontinuous (discrete) data and deciding which type of graph to use, was a problem for many students. Tairab and Khalaf Al-Naqbi (2004:130) also found in their study of Grade 10 students from the United Arab Emirates and Brunei that *"students often confuse types of graphs and do not necessarily differentiate between the various forms of graphs (e.g. histogram, line graph, bar chart, etc.)"*.

- ***Using line of best fit***

Even though this problem was not mentioned by the teaching staff during the interviews, it was identified during the class observation to be the second most frequent problem that the students had. Eleven students struggled to see that they had to draw a smooth curve when given a cluster of points, but instead had a tendency to join all the points so that the line went through all of them, even when this was not appropriate. This supports research findings by McDermott *et al.,* (1987) in his study of university students in the USA (Chapter 1, Table 3, p. 12).

- ***Extrapolating***

To extrapolate means *"to estimate (a value of a function or measurement) beyond the values already known, by the extension of a curve"* (Collins English Dictionary, 1991). One lecturer during the interviews explained that,

> *"They don't know what extrapolating means. Sometimes with extrapolating they have to understand that it doesn't always draw in the line of the curve, it has to flatten out and as a graph or when the enzyme is all occupied then it has to go flat, or when enzymes just denature, for example at high temperature, that the graph goes down because all the enzymes are dead. So these things they have to really learn"*. (Lecturer #4).

In the class observation two of the 43 students were seen to have a problem with extrapolating (Table 23). This problem was not identifiable in the examination questions.

- ***Using log graph paper***

One lecturer who teaches the medics reported that

> *".........we do also ask them to plot some non-linear data on logarithmic graph paper, and they seem to have problems with that as well, in understanding the log-graphing rules"*. (Pilot interview).

This was confirmed by the researcher during the observation of the practical session. Ten students had a problem using log graph paper, although only two reported (at the end of the practical) having had the problem. The analysis of the exam papers (see Table 22) shows that although 82.2% of the students were able to recognize different types of log graph paper (Question 11), only 43.9% were able to determine correctly which type of log graph paper to use when provided with tabulated data (Question 12).

Brasell (1990) points out that students find it more difficult to interpret curved graphs than straight ones, and that while "*logarithmic and exponential scales can be used to convert a curved graph to a linear one, ... these scales are conceptually more difficult to interpret than natural scales*" (Brasell, 1990, 74).

- ***Carelessness***

One lecturer mentioned that,

> *"Other problems with actually drawing up graphs are often just carelessness in terms of not plotting points accurately"*. (Lecturer #5)

Table 26 summarises the lack of mastery achieved by the College of Science students (n = 65). It needs to be borne in mind that these students had specifically been taught graphing skills, including the basic rules of graphing. Of the 65 students who wrote the examination, 9% were unable to provide a suitable title for the graph (Question 7a). All had been taught the importance of doing this, so omitting it seems to be just carelessness. Table 26 also shows that 85% of the students forgot to supply (or could not) the units of measurement for the *y* axis. 8% and 22% of the students (respectively) could not label the x axis and y axis correctly. A surprising 49% of these students failed to label the line clearly.

3.2 NEEDS ANALYSIS

The last research question was aimed at finding out possible strategies needed to rectify graphing problems experienced by the students. Three specific questions (i.e. how, when and who should teach the skills) were asked in the interviews of the teaching staff, in order to answer the following research question.

Research question 4.	**What strategies do first-year biology lecturers believe are needed to rectify graphing problems experienced by their students?**

3.2.1 How graphing skills should be taught

One lecturer suggested a combination of basic lecture followed by an exercise

> *"Well they should definitely do them on a practical level, so, ehm, they should, perhaps, it should be a combination of a basic lecture outlining graphing skills and then some actual exercises where they can .... eh do graphs themselves based on some data sets that they are given or some examples that they are given, and if the classes are, eh, are small enough perhaps they could even make some graphs on .... on a computer"*. (Lecturer #1).

Tairab and Khalaf Al-Naqbi (2004) state that *"With the advent of technology and computer tools, graph construction exercises become much easier because computers can perform most of the actions in a more efficient manner"*. Lecturer #1 tentatively talks about doing graphs on computers, which the lecturer in the pilot interview had said this is how most graphing is done these days

> *" This practical we do ... for medical students, its entirely paper-based. They work entirely with graph paper. Ehh, of course nowadays hardly anybody uses graph paper. You type your data into your computer, and the computer programme generates the graph for you. And the ...... I think that eh, this kind of exercise, eh it teaches, well it attempts at least to teach the students the underlying principles of constructing a graph. Whereas if you ... if you just type your data into a spreadsheet or something, the spreadsheet will do the graph for you. You'll get the graph but you may not actually understand what's going on underneath, and how the graph was actually constructed"*.(Pilot interview)

This raises a very interesting issue regarding the modern trend to let the machine do the graph for you, and whether students will perhaps not understand the graph so well because they may not have constructed it. However, the lecturer from the pilot study seems to have a solution to that when he goes on to say,

> *".......you'd have to devise a ... eh, exercises, so that the students have to make decisions about what scales they were going to use, how the graph was going to be designed. It mustn't be eh, mustn't be generating the graph automatically, as would happen if you were using a spreadsheet programme to do it".*

Table 27. Lecturers' and teaching assistants' opinions on how graphing skills should be taught (n=9)

Explanation	Frequency	
By explicitly explaining important aspects to the students.	L2, L3, L5, T1, T3.	5
By explicitly teaching graphing skills.	L1, L5, T4.	3
By giving them practice in using the skills, i.e. paper-based exercises.	L1, L2, T2, T3.	4
By providing opportunities for students to apply graphing skills in new situations.	L2, L5.	2
By providing feedback for students who exhibit problems.	L5, T2.	2
By allowing students to use computers to generate graphs. The problem here is they often don't understand what it is they are doing because the computer does some of the work, e.g. calibrating the axes.	L1.	1
By making better use of audio-visual aids like overhead transparencies.	L2, L4.	2

From Table 27 it can be seen that explicit teaching of the skills and explanation of important aspects to the students seems to be the most popular advice given generally by the teaching staff, in addition to giving them practice in using the skills (notably paper-based exercises). One lecturer emphasised the need to practice.

> *"The kind of skill that I think that many students do not have, and it is something that we, I think should concentrate on perhaps, in, in putting across, very early, during the first, ... at the first-year level, is what graphs tell us. Eh, and the only way to do this I think, is to present students with an incredible variety of graphs, ehm, which I'm not convinced that they get, ehm, in that first graphing practical of theirs. A large variety of graphs and going from the very simple, right through to the very complex multi-graph diagrams".* (Lecturer #2).

As pointed out by Cave (1995), intensive practice is necessary to develop graphing skills and students need to have as much experience as possible with a wide variety of graphs (section 1.2.2).

3.2.2 When skills should be taught

There seems to be a difference of opinion amongst the teaching staff on when graphing skills should be taught, as shown in Table 28.

Table 28. Lecturers' and teaching assistants' opinions on when graphing skills should be taught (n=9)

Category	Explanation	Frequency	
In practicals.	A whole practical devoted to graphing skills.	L1, L4, T1, T4.	4
In tutorials.	Various aspects of graphing must be explained, e.g. dependent and independent variables.	T1.	1
In a specific lecture.	Early on in the first-year, a specific time should be scheduled for teaching graphing skills.	L2.	1
In lectures whenever needed.	Explanations should be given during the lecture on an *ad hoc* basis whenever a new principle is needed.	L3.	1
In self-study projects.	Students should do small experiments in which they collect data and are expected to draw their own graphs and interpret them.	L5.	1

Several options were put forward. The most popular option seemed to be specific teaching of the skills, although people did not all agree on where this should be done. Four of the teaching staff felt that the best place to teach the skills would be in practicals, one teaching assistant suggested the tutorials, and one lecturer felt it would be best done in a specific lecture. The second option (mentioned by only one lecturer) was to teach the skills on an *ad hoc* basis when the need arose. The third option, given by the lecturer from the College of Science, was that students should do it on their own in a self-study project.

3.2.3 Who should teach the skills

According to the lecturer interviewed in the pilot interview, it is very difficult to say who should actually take responsibility for teaching graphing skills at university level, as portrayed by the following quote,

> *"Eh if one is thinking about, eh, let's say first-year science students, first-year science students would be, ehm, taking a number of different first year courses, maybe about five, so they could be taking biology, physics, chemistry, and, and they could be using graphing in all of those subjects, so ehm, thinking of first-year, with all of those students, it might almost be an idea for them to have a centrally organised course on graphing skills, so that, otherwise there'll be a risk, there's a risk that each of those departments teaches graphing skills. So they get duplication. ....Ehm, ehm, so it makes it a bit difficult to see exactly who should be teaching this, unless there's some sort of overall coordination across the whole of first-year".* (Pilot interview)

But an interesting comment on this suggestion, which seems so sensible, is that research has shown that students struggle to transfer skills, and if taught in maths for example, many cannot then apply what they have learned in biology (Brasell, 1990; Millar *et al.*, 1994) - (see Chapter 1, section 1.2.4).

Over and above teaching graphs at university, only one lecturer suggested that school teachers should also be responsible for teaching basic knowledge of graphs.

> *"I think that the students coming in essentially to do a science degree need to know about graphing because it's an essential part of any, ... any aspect of the sciences, ehm, ... because graphs are such an important way of actually communicating information. And I think that it probably needs to be taught both in the school and, ... and here. I think what we do is we, ... it would be good if students came in with that knowledge and all we were doing was reinforcing it or putting it in a particular subject context. But I think that we can't assume that, and we have a responsibility, if we want the students to know how to graph or to use graphs, we need to teach them that".* (Lecturer #5).

Table 29. Lecturers' and teaching assistants' opinions on who should teach the skills (n = 7)

Category	Explanation	Frequency	
School.	School teachers should teach basic knowledge of graphs.	L5.	1
University.	Tutors / Lab staff.	L4, T1, T2, T3, T4.	5
	Lecturers.	T1, T2.	2
	Students themselves.	T1.	1
	People from the education field should design special practicals or tutorials.	L2.	1

Table 29 illustrates that all the teaching assistants agree that graphing skills should be taught at university by the tutors or the laboratory staff. It is interesting to note the apparent contradiction of opinions, in that earlier on all the teaching assistants agreed that they **expect** the students to be able to construct graphs when they enter first-year.

Not all of the staff members interviewed had an answer to the question of who should teach the skills. One lecturer blatantly admitted that *"I have no idea"* (Lecturer #1), and one Teaching Assistant confessed that *"I don't know I guess whoever is, eh, coordinating the first-year labs and then the demonstrators, obviously"*. (Teaching Assistant #3).

3.3 CONCLUDING REMARKS

The results obtained from the interviews and the analysis of the question papers showed many of the difficulties in understanding and using graphs identified by Brasell (1990). Firstly students' ability to work with graphs seemed to be superficial. Brasell (1990) suggests this happens when students focus on the use of the rules of graphing rather than an understanding of the functions of graphs and what they show. A number of students in this study appeared not to know or were unable to apply, the graphical “grammar” for encoding and decoding information in a graph. Secondly, many students seemed not to understand how to link the graph with the variables being depicted and they may not have understood the substantive concepts being graphed, as shown in questions 5 and 8 of the College of Science examination (Tables 24 and 25), where for many of the concepts less than a quarter of the class answered correctly.

The results of the class which had received sustained and systematic training in graphing (the College of Science students) revealed that many students still had problems with graphing skills, in spite of all the teaching. Brasell (1990, 82) warns that

> *“Explicit instruction is often limited to routines for plotting and reading data points in simple graph formats. These algorithms work well for constructing graphs as part of laboratory reports as long as guidelines indicate which variables to plot on which axes. They are also sufficient for recognizing the appropriate graph in multiple-choice graphing test items. However, the algorithms are not adequate for interpreting graphs or designing graph formats from raw data.”*

Stories about teaching in the College, however, suggest that their teaching of skills goes beyond the simple provision of hints on how to do the skill.

In the web-based materials to be developed to teach graphing skills to first-year biology students, cognisance needs to be taken of these problems, and the instructional design will be based on a firm foundation of what learning theory and educational research has shown about effective teaching and learning.

CHAPTER 4

SUMMARY OF FINDINGS, AND RECOMMENDATIONS

The aims of this chapter are to discuss the limitations of the study and how they were dealt with, to summarise the findings from this study, and to discuss the implications and recommendations for further research.

4.1 DISCUSSION OF THE LIMITATIONS OF THE STUDY

In this study, as is almost always the case with any other educational research, there are certain factors that threaten the validity of the research, which the researcher does not always have absolute control of. The reader needs to take these limitations into consideration in order to make informed decisions when interpreting the findings.

4.1.1 Small sample size

The problem with a small sample is that it is less likely to represent the population, hence no generalisations can be made about that population from the results of that sample. The number of teaching staff interviewed might seem low, but in fact it was all the people involved in the teaching of graphing skills at first-year in this particular university, i.e. it comprised the whole population and was not just a sample. Because only one university was studied, the sample was too small to support a generalisation of the results to the larger population of the country.

4.1.2 Lack of interview experience

Because the researcher was a novice in conducting interviews, this might have had an effect on the process of collecting data, hence affecting the findings of the study. Measures were taken to minimize the inexperience problem by conducting an intensive literature review and doing mock interviews (see section 2.4.2). In retrospect, the researcher realized that there were problems with the interviews, e.g. after looking at the transcripts over and over again, the researcher realized that in some cases more probing could have been done. In this study, this could mean that the researcher might have missed some important information from the teaching staff that would probably have influenced the interpretation of the findings.

4.1.3 Validity of the research methods and findings

Validity is defined by Lindquist (1989, cited by Sanders and Mokuku, 1994), as the ability of an instrument to measure accurately what it is intended to measure. Sanders and Mokuku (1994) point out that there are always two facets of validity, i.e. on one hand validity refers to the likelihood of the results obtained from the instrument being an accurate reflection of "reality", on the other it refers to the plausibility of the inferences made by the researcher. According to Fraenkel and Wallen (1990: 127), *"The drawing of correct conclusions based on the data obtained by use of an instrument is what validity is all about"*.

In this study several steps were taken to try to improve the validity of the instruments used.

Interviews.

- In this study measures were taken to improve the validity of the interviews by taking the interview schedule through several steps of face-validation, during which an expert in science education looked at the instrument to check for the appropriateness of the questions in the instrument (see section 2.4.2).
- Also, the interview schedule was first piloted to help the interviewer to improve on the techniques chosen for asking questions and to probably give an idea of the kind of information and the kind of responses that are likely to be obtained (see section 2.4.2, page 32).

Observations.

- The validity of findings when using observation methods is threatened by the influence of the observer on the people being investigated. In this study the researcher noticed that students had an attitude of "not wanting to look stupid" because when they asked questions from the teaching assistants (in some cases anyway), they would abruptly change the subject and pretend everything was fine when the researcher tried to come closer in order to get their questions. So in some cases the researcher had to get the students' problems from the teaching assistants. This could affect the results in that it was highly unlikely that the researcher would get all the problems experienced by the students, hence the problems would be underestimated.

  Observer influence could have been minimised by introducing the researcher to the group early, and allowing a number of days for the research subjects to become familiar with the researcher's presence, before observations start being made, as recommended by McMillan and Schumacher (1993). This was not possible in this study because there was only one graphing practical and it was not possible for the researcher to spend time with the subjects prior to the observations.

- Students' self reports on problems encountered during the practical may not be a true reflection of their problems because it was at the end of the practical and students were in a hurry to leave and may not have wanted to spend their time chatting with the researcher for no apparent gain. Thus the results reported may have been an underestimate of the actual problems experienced by the students. Certainly the observed results seemed to confirm this suspicion - nine students were observed to have the three interpretation problems investigated, i.e. determining coordinates (one student), describing relationships (three students), and interrelating graphs (five students), but only one student admitted to having interpretation problems, specifically describing relationships (see Chapter 3, Table 23). Also, during the pre-practical talk, the lecturer had mentioned that students often struggle with log graphs. A total of ten students were observed to have problems with using log graph paper, but only three students admitted to having this problem.

Document analysis.

- One problem with using the examination questions to make inferences about graphing difficulties is that the examination questions were not set to test individual isolated skills, i.e. the questions analyzed were examination questions that already existed, and were not designed for the purposes of this research. The questions that were used in fact tested "integrated skills" (complex tasks made up of a number of "basic skills" - see section 1.1.4, Chapter 1) that couldn't be separated out to make it clear which skill was being tested. This is illustrated in Table 22 in Chapter 3, which shows the multiple choice questions of the medical students' question paper. Each question tested more than one skill, e.g. question 15 shows that 80% of the students had a problem answering this question, but it is not easy to pinpoint which of the four specific graph construction skills tested was the actual problem for the students. This issue created problems during the analysis of results in that it was extremely difficult to determine the individual basic graphing skills the students lacked as each wrong answer could have been a result of a lack of one or more skills.

  None of the instruments used in the research described in the papers reviewed for this study were reproduced in the papers (e.g. as appendices). These would have given the researcher easy access to items testing for specific graphing skills to use in the present study. Because of time constraints the researcher made no attempt to get tests specific to graphing skills, since all the literature reviewed for this study was overseas based, and there was not enough time for the researcher to make contact with the authors so as to request their graphing tests that were designed to test specific graphing skills. Also, the scope of the study (research had to be finished in six months) prevented the researcher from designing his own tests from scratch.

4.2 SUMMARY OF FINDINGS

In concluding this report, the findings of the research are discussed in relation to the four research questions asked at the beginning of Chapter 2.

Question 1:

What graphing skills do the biology teaching staff at the University of the Witwatersrand expect from students entering first-year biology?

- Although the teaching staff were asked about skills expected from students "when they enter first year" and "during the course" the staff did not seem to see any difference (see section 3.1.1, Chapter 3).
- Seven of the nine teaching staff expected students to be able to construct simple graphs when they arrive at university.
- Six expected the students to be able to construct graphs from simple experiments during the course of the year. In particular, all the teaching staff expected the students to use line graphs.
- Two teaching staff involved with the medics expected students to use log graphs, and another two lecturers expected students to use regressions and scatter-graphs, which are not common everyday use graphs.

Question 2:

What graphing skills do first-year biology teaching staff at the University of the Witwatersrand teach and how?

- As expected, all the teaching assistants confirmed that they do not teach the skills, as explained by one teaching assistant when she said they only answer the students' questions and mark their lab reports.
- Three lecturers stated that they teach the skills in specific practicals because they do not expect the students to have the skills when they come to university.
- Two lecturers said they did not have a strategy for teaching graphing skills - one lecturer said he teaches it by integrating it into the course, and the other lecturer said he teaches graphing skills only when he sees the need.

Question 3:

What graphing problems are experienced by first-year biology students at the University of the Witwatersrand?

- Seven of the teaching staff (including the "pilot" interviewee), said that their students have problems with graphing.
- Although the teaching staff mentioned a variety of difficulties, both in constructing and in interpreting graphs, very few problems were mentioned by more than a small proportion of the staff. As shown in Table 21, only one interpretation problem and one construction problem were

mentioned by more than two teaching staff (four teaching staff). The rest of the problems were mentioned by either one or two teaching staff.

- The most common *construction* problem identified during the practical observation was scaling axes, (noted in 15 out of the 43 students), whereas the most prevalent graph construction problem identified by the teaching staff (four teaching staff) was identifying the dependent and independent variables, or deciding which variable should be plotted on which axis.
- Fewer problems were identified with *interpreting* graphs, the commonest (that students struggle with the quantitative description of what the graph is showing) being mentioned by four teaching staff and confirmed in the analysis of the College of Science question paper.
- Question 19 in the medics question paper (Table 22) shows that 58% of the students do not understand the fundamental properties and functions of graphs in representing relationships among variables. This is confirmed in the results of Questions 5a and 5b of the College of Science question paper (Table 24).
- Other specific skills tested (that were not evidently substantiated in the results chapter), which students were lacking, included the knowledge and understanding of the subject content, as well as knowledge of the shape of a rectangular hyperbola and the trends it represents, among other skills, as illustrated by the low percentage of correct responses and high number of non-responses in the multiple choice questions.

Question 4:

What strategies do first-year biology teaching staff believe are needed to rectify graphing problems experienced by their students?

- Five teaching staff said that the best way to teach graphing skills would be explicit explanation of important aspects of graphs to the students.
- Four teaching staff said giving students enough practice such as paper-based exercises would be the best way to teach these skills.
- Also, four teaching staff said the best time to teach the skills would be during the practicals.
- Five teaching staff suggested that the teaching of these skills was the responsibility of the university, specifically lab staff or tutors, not the schools.

Analysis of the results of the class which had received sustained and systematic training in graphing (College of Science) revealed that many students still had problems with graphing skills, e.g. 85% of the students could not even indicate the units of measurement when asked to plot a graph from given data, whereas 49% could not label clearly a line they drew themselves, in addition to 38% of students who could not choose a suitable scale and another 38% who were unable to read an x-axis value (see Table 26). This means that other ways of teaching the skills need to be considered if there is serious concern about improving students' graphing skills.

4.3 IMPLICATIONS AND RECOMMENDATIONS

This research revealed that some of the first-year university biology students investigated in this study, although they might have had some experience in using graphs from high school, still need to be taught how to construct a simple graph of scientific variables.

4.3.1 Implications and recommendations for teaching

Teaching staff need to be aware of the difference between teaching skills and simply asking the students to use the skills, as warned by Beyer and Charlton (1986). This study suggests that maybe a more effective way of teaching skills on scaling axes and identifying or plotting the dependent and independent variables when teaching graph construction, as well as the ability to tell the meaning of the graph when teaching graph interpretation needs to be found, as these seemed to be the areas where students struggle the most. This suggestion is supported by the fact that these skills were specifically taught in the College of Science, yet it did not help. The following recommendations are based on what research or learning theory suggests, and are mentioned here as suggestions for teachers to consider trying once they are aware of the problems experienced by students, and are really willing to do something about it.

- It might help the students if university curricula were designed to allow for enough time to teach graphing skills. One practical session for the whole year, or teaching the skills on an *ad hoc* basis may not be enough for the students to learn these skills.
- A suitable environment for students to explicitly practise construction and interpretation of graphs is something teachers may consider developing. According to Beyer and Charlton (1986), students cannot just acquire skills by themselves. Skills only develop after sufficient active teaching and intensive practice, a strategy that was also pointed out by Cave (1995). Tairab & Khalaf Al-Naqbi (2004) found in their study that students with more opportunities to practice graphing perform better than students who do not have that privilege.

As mentioned earlier in Chapter 1 (section 1.4), the ultimate goal of this study was to produce and evaluate a web-based computer programme to improve first-year university biology students' ability to construct and interpret graphs. Bearing in mind that this study has shown that graphing skills seem to be very difficult to master, great care needs to be taken to design a package that is **effective** in teaching these skills. The underlying assumptions that will guide the development of this instructional package are that the way graphing is being taught in South African schools does not allow the kind of cognitive involvement which leads to meaningful learning, which can be facilitated by well-designed computer software. In developing this package, the objectives would be to challenge pupils with key questions which encourage the type of thinking that goes beyond the simple reading of information from the graph and description of a variable, and leads to an interpretation in terms of a generalized relationship between variables.

4.3.2 Implications and recommendations for research

Further research is needed to find out whether the graphing problems identified in this study are generalizable to other studies similar to this. Due to the time limit and the size of the study, there were certain aspects that the study could not cover, and which would provide useful topics for further research.

- It would be useful to see whether students who are specifically taught specific graphing skills, and provided with lots of practice would experience the same difficulties with graph construction and interpretation, or whether basic training in graphing skills would improve their ability to use graphs more effectively to help them understand science concepts.
- It would also be helpful to see whether the use of graphing tests specifically designed to test specific graphing skills, i.e. tests that allowed frequency counts of individual graphing problems, would shed more light on the nature and extent of the particular graphing problems first-year biology students are struggling with.
- Other methods need to be considered for investigating the problems when interpreting or constructing graphs, due to the "intergrated skills" situation, in order to understand the specific basic skills with which students are struggling. One method could be the talk-aloud protocol. In this method a student is given a graphing problem, and then asked to talk-through their thinking processes as they are solving the problem, whilst the researcher is recording the student, so as to give the researcher an insight of what the student is thinking. This allows the researcher to gain further details to explain students' graph construction and interpretation problems, information that would not be obtained from marking tests.

- Additional studies could be conducted to investigate the effects of different teaching methods and learning environments on students' ability to interpret and construct graphs.

4.4 CONCLUDING REMARKS

As argued in Chapter 1, graph interpretation and graph construction are important skills for students to acquire, and the lack of these skills is a handicap in learning science. Science students who are able to determine the meaning of a particular graph by looking at it are putting their knowledge to work. This research may provide the basis for further research which could provide more information on teaching the skills of graphing.

This study has shown that most first-year teaching staff expect high school teachers to teach graphing skills, hence they do not teach the skills but only expect the students to use the skills. Unfortunately a number of first-year students at this particular university appear lack these graphing skills. The extent of this lack of graphing skills is not clear from the students' self-reports but question paper analysis gave some indication of the nature of the problem. From the interviews, the comments by some teaching staff indicate that there is no clear strategy for teaching these skills, and this does not help the students in any way. The study provides evidence that many students do not learn these skills at high school. Therefore, it appears that more attention may need to be paid to specifically teaching these skills. However, it has to be borne in mind that the College of Science course makes a concerted effort to teach graphing skills, yet their students still have problems.

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APPENDIX 1

Interview schedule for first-year biology lecturers.

Interview schedule for first-year biology lecturers

MAIN QUESTION	POSSIBLE PROBE QUESTIONS	REASON FOR ASKING
1. What first-year course do you teach?		
2. In that course do you expect your students to use graphing skills.	If "yes", then ask: – Please explain what you expect them to do with graphs.	To determine skills lecturers require students to use.
3. What graphing skills do you expect students to have when they enter first-year?	If they don't seem to understand, then ask: – What do you expect them to be able to do with graphs when they arrive in first-year from school. If they dry up, then ask: – From where do you expect them to get graphing skills? – Do you expect them to be able to read and interpret graphs? – Do you expect them to be able to construct graphs?	To determine the lecturers' expectations of the students when they come to university.
4. Which types of graphs do you expect your students to use in your course?	If they don't seem to understand, then ask: – Do you expect them to use line graphs for instance? – Which other types of graphs do you expect them to use other than line graphs?	To establish the types of graphs used in the first-year biology courses.
5. In the first-year classes you have taught, do students seem to have graphing problems?	If "yes", then ask: – Can you describe the graphing problems they have that you have picked up in your teaching? If they dry up, then ask: – Do they have problems in constructing graphs? – Do they have problems in interpreting graphs?	To establish nature and extent of graphing problems of first-year biology students at the University of the Witwatersrand.

MAIN QUESTION	POSSIBLE PROBE QUESTIONS	REASON FOR ASKING
6. Do you think first-year biology students should be taught graphing skills if they seem to lack them?	If "yes", then ask: – How should the skills be taught? – By whom should the skills be taught? If "no", then ask: – How do you think they will be able to acquire the skills?	To determine whether, if such skills are needed and missing, it is the lecturers' responsibility to teach them at university level.
7. What do you do, if anything, about teaching these skills?	If they dry up, then ask: – Do you specifically teach graphing skills? – Are there any special measures that you undertake to improve the students' graphing skills?	To establish what, if anything, is being done to teach these skills to first-year students, if they are needed but lacking.
8. Do you use any particular strategy to teach graphing skills?	If "yes", then ask: – What strategies do you use to teach graph construction? – What strategies do you use to teach graph interpretation?	To establish if the lecturer believes graphing skills are important enough to necessitate emphasis on students acquiring those skills.
9. Do you assess graphing skills in your course?	If "yes", then ask: – When do you assess the skills? – How do you assess the skills?	To find out if the lecturer believes graphing skills warrant any assessment.
10. Do you have test or exam papers for me to look at the questions?	If "yes", then ask: – Do the questions on graphs count significantly in the tests or exams?	To determine the importance of graphing skills in the course.

APPENDIX 2

Interview transcripts

Interview transcripts

Pilot interview

I: Interviewee **R: Researcher**

Introductory statement: Oh first of all I am conducting a study for my MSc about the development and evaluation of a web-based computer programme on graphing skills for first-year university biology students. I am hoping that you could help me by responding to a few questions. I understand that you might be teaching at different levels, so I would like you to keep details of your answer at the first-year level. Also, if my questions are not clear, I would like you to tell me. You are free to elaborate on any matter that I might have left out, and you feel is important and relevant. I have also provided you with a pen and paper in case you want to write down some thoughts or ideas.

R: My first question is **what first-year course do you teach?**

I: The first-year course ... it's the medical biology course. It's actually called " introduction to medical science", but it's just biology. The name is a bit confusing anyway. Ehm, and ehm in this course we have just one practical on graphing skills, so it's not a great amount, just one practical. Ehm, and ... and because of the size of the course, the size of the class it's about ...... to 500 students altogether, split into three groups. Ehm, I have to admit that I don't really see a lot of what the individual students are doing. So I'm sort of running around supervising and organising.

R: **In that course do you expect your students to use graphing skills?**

I: Ehm yes. Ehm in other practicals later on, well, later on in the first block, the same block, ehm they do use graphing skills. But because of the way the course is run, the other practicals aren't run by me, they're run by other people, so ehm, although I, I run the practical on graphing skills I don't actually see them using those techniques later on in the course.

R: Can you please explain what you expect them to do with graphs.

I: Ehm, well, ehm, in the in the practical on graphing skills it really covers just about the entire range. Ehm, [pause] it starts off by covering the sort of data types, ehm, talks about variables and qualitative data, discrete quantitative data, continuous quantitative data. So they are expected to be familiar with all words which we are using and what they mean, and they are then also introduced to dependent and independent variables. Ehm, eh, then they they cover just about every type of graph which one could think of. They cover the types of line graphs and eh histograms and pie charts and all those kinds of things. So it's really a very broadly based eh introduction eh to graphs, or graphing skills in general. Ehm, I suppose in essence it covers things like dependent and independent variables and types of data, ehm. Basically there's some stuff which isn't necessarily directly related to different skills, it's really about the data............ And we expect them at the end of that practical to eh be familiar, eh with all those types of graphs.

R: **What graphing skills do you expect students to have when they enter first-year?**

I: When they enter first-year, ehm, [pause], I think it's more or less assumed they don't have any. We do actually comment in the introduction to the practical, they've probably already seen graphs in newspapers and on television and so on. But in this practical we essentially start from scratch with the assumption that they don't know anything about graphs.

R: So in other words you don't expect them to be able to do anything with graphs?

I: Ehm, not really, no, no.

R: **Which types of graphs do you expect your students to use in your course?**

I: Ehm, well the way its run, as I said the way it's run ... in some of the later practicals they do have to use ehm graphs, ehm [paging through the practical manual] I don't have any practical examples. In the next practical, ehm, which is one on enzymes and enzyme kinetics, ehm, they are required to plot enzyme reaction rates against time and things like that.

R: **In the first-year classes you have taught, do students seem to have graphing problems?**

I: Eh, yes I think they do have problems, yes.

R: *(Probe by nodding the head).*

I: Ehm, just before you came along here I was wondering, it might be worthwhile interviewing some of the TA's.

R: Okay, thank you.

I: Have you thought about that? Because they are the ones who have much more direct interaction with the students.

R: Okay.

I: So it certainly in these very big first-year courses, you know ... eh, and it might be worth your while talking to them. Ehm, I mean they ... they ..., the particular problems that I've personally picked up were one, difficulties with designing eh suitable scales and things which fit on to graph paper, appropriately. You know, without everything being squashed up at one end or running off the scale.

R: So now as you see they have problems with constructing graphs?

I: Well, in deciding what scales to use in constructing graphs, yes. Ehm, and then ehm, we did also, we do also ask them to plot some non-linear data on logarithmic graph paper, and they seem to have problems with that as well, in understanding the log-graphing rules.

R: Do they have problems in interpreting graphs?

I: Ehm, it's difficult for me to say. With this particular practical that I run, ... isn't really related to, very much to interpreting. There are one or two sort of interpretations, eh, but it's really much more concerned with how graphs are constructed, ...and not how graphs are interpreted.

R: Okay. **Do you think first-year biology students should be taught graphing skills if they seem to lack them?**

I: Yes I think they should be taught graphing skills.

R: How should the skills be taught?

I: Ehm, well it's a very practical subject, and, ehm, so ehm I suppose if it has to be taught, there have to be practicals on it. Ehm, when I first started ... let me just backtrack a little bit [paging through the practical manual]. This practical we do ... for medical students, its entirely paper-based. They work entirely with graph paper. Ehh, of course nowadays hardly anybody use graph paper. You type your data into your computer, and the computer programme generates the graph for you. And the ...... I think that eh, this kind of exercise, eh it teaches, well it attempts at least to teach the students the underlying principles of constructing a graph. Whereas if you ... if you just type your data into a spreadsheet or something, the spreadsheet will do the graph for you.

You'll get the graph but you may not actually understand what's going on underneath, and how the graph was actually constructed.

R: So do you think it would be a wise idea to teach graphs using a computer?

I: Yes I think it could be done using computers, but eh, you know, you'd have to devise a ... eh, exercises, so that the students have to make decisions about what scales they were going to use, how the graph was going to be designed. It mustn't be eh, mustn't be generating the graph automatically, as would happen if you were using a spreadsheet programme to do it.

R: So in your opinion by whom should the skills be taught?

I: Ehm, [long pause] sorry I was thinking about several things .... factors. Eh if one is thinking about, eh, let's say first-year science students, first-year science students would be, ehm, taking a number of different first year courses, maybe about five, so they could be taking biology, physics, chemistry, and, and they could be using graphing in all of those subjects, so ehm, thinking of first-year, with all of those students, it might almost be an idea for them to have a centrally organised course on graphing skills, so that, otherwise there'll be a risk, there's a risk that each of those departments teaches graphing skills. So they get duplication. Ehm, [slight pause] and also at first-year science courses, different students do different combinations of topics, which also makes again more difficult with the graphing skills that are taught about in individual courses. And again it makes it difficult to ....coordination for a particular student. Ehm, in the case of medical students, ... the ones I am dealing with ... they have a fixed curriculum, so ehm, [pause] there's not the problem of different students doing different combinations of courses. But again they are doing biology, they are doing some, some physics, some psychology I think, and again they, they could be using graphing skills in any one of those courses. Ehm, ehm, so it makes it a bit difficult to see exactly who should be teaching this, unless there's some sort of overall coordination across the whole of first-year. Well was that the sort of thing you meant?

R: So for you **what do you do, if anything, about teaching these skills?**

I: Ehm, well, we have this practical, this one practical in first-year [paging through the manual]. Have you seen it?

R: No I have no clue. It's only one practical?

I: It's just one practical. Ehm, but then ... then of course since since they do use graphs in later practicals, there's a certain amount of reinforcement in those later practicals.

R: So do you specifically teach graphing skills, or you just expect them to have them?

I: We, we, in this, we teach, specifically teach, graphing skills.

R: So are there any special measures that you undertake to improve the students' graphing skills?

I: Ehm, well this, this practical that I run, ... presumably they have better graphing skills at the end of it than at the start of it, so yes, we do that. And ehm, when they use graphs later in the course I, I assume the TA's look at the graphs they draw and see if they are okay, and if there are problems with them, but as I say I don't teach that particular section and the best person to talk to might probably be the TA.

R: **Do you use any particular strategy to teach graphing skills?**

I: Ehm, [pause] well not, not specifically except that we have the practical which we use, and then the follow-up usage of graphs in later practicals.

R: **Do you assess graphing skills in your course?**

I: Ehm, yes we do. Ehm there's a practical ..., well okay yes, in, in two ways. One, ehm, the students get practical marks for their practical reports, and, so ehm, there will be an assessment at the end of this practical on graphing skills, how well they've done. The assessment is made by the TA's, and, and then when they use graphs in later practicals .... again there will be some assessment by the TA's on how well they constructed and produced those graphs. And then they do also have a, a practical test, which in this case .... this year, was actually a multiple-choice. Ehm, but there were [flips through the pages of a test paper], ehm there were about four or five questions that I've put in here related to, to graphing, and so they ... they are assessed both on the practical work they do and also as a, as a test in the middle of the year. Martie has this.

R: I was about to ask that question, **do you have any test or exam papers for me to look at the questions?**

I: Ehm, yeah yes, we do. Eh in fact more than just the questions. This is a multiple-choice. I have actually got a set of statistics on the answers from the class, you might find useful. But because there's only four questions it won't tell you an enormous amount.

R: Because my last question was going to be 'do the questions on graphs count significantly in the tests or exams?'

I: Ehm, [hesitantly] I don't, I can't tell you what the actual weighting is. Ehm, the answer is, is no, a very small proportion of the assessment.

R: Thank you very much for your time.

Interview 1: Staff member #1

I: Interviewee **R: Researcher**

Introductory statement: I am conducting a study for my MSc about the development and evaluation of a web-based computer programme on graphing skills for first-year university biology students. I am hoping that you could help me by responding to a few questions. I understand that you might be teaching at different levels, so I would like you to keep details of your answer at the first-year level. Also, if my questions are not clear, I would like you to tell me. You are free to elaborate on any matter that I might have left out, and you feel is important and relevant. I have also provided you with a pen and paper in case you want to write down some thoughts or ideas.

R: Question number one, **What first-year course do you teach?**

I: Ehmm, in particular I teach the ... the medics, which is 'human biology'.

R: **In that course do you expect your students to use graphing skills?**

I: Well, well in [pause], they are actually taught a, a practical in which they, they use graphing skills. So there's a practical devoted to graphing skills, but I don't actually run that, that practical. So they do get experience early on in the course. What I expect them to know is ehm, basic interpretation of, of graphs. So during the lecture period I might show them a, a graph, and then obviously that graph will show some relationship that they need to understand. So although I don't actually make them .... I sometimes, in an exam, ask them to draw a graph, so they need to know basic interpretation of, of graphs and what relationships a graph might be able to show.

R: So you don't expect them to know much of <u>constructing</u> graphs.

I: They should know the basics.

R: **What graphing skills do you expect students to have when they enter first-year from high school?**

I: Oh, they don't need any graphing skills. [Pause]

R: *(Probe by nodding the head).*

I: So they get all the basic graphing skills in a single practical. By the time I, I lecture to them ehm, they've already had that practical.

R: **Which types of graphs do you expect your students to use in your course?**

I: Ehmm, just basic linear .... just graphs showing, ehm ... basic scatter-plots, and sometimes histograms. Quite .... fairly elementary graphs, but mainly, mainly scatter-graphs and, ehm, occasionally maybe a regression, but not .... they wouldn't need to know .... they would just need to know the relationship on that, on that regression, nothing about the statistics.

R: Do you expect them to know like, the types like line graphs?

I: Yes, ja line graphs.

R: And pie graphs?

I: Ja.

R: **In the first-year classes you have taught, do students seem to have graphing problems?**

I: Ehmm, [long pause]. I don't know if .... if ... [pause] I've never really gone into enough detail to really determine that, ehm. So when .... when I teach them, ehm, earlier .... in an .... in an earlier question I said that I don't expect them to know graphing skills, and not .... we don't expect them to know graphing skills from high school, but as I mentioned before, ehm, they do a practical in which they do graphing skills. So, ehm, I assume that they have that .... that knowledge, ehm. And not having taught that specific practical I'm not sure if they .... what sort of problems they .... they have. [Pause].

R: *(Probe by nodding).*

I: I don't know if that really answers the .... the question, ehm, they can obviously, students sometimes have problems and then if they come and ask you you can explain it to them but, uh ... you know, I don't know if the problems that they have are really related to graphing skills so much as understanding the relationships they need.

R: (*Probe by nodding*).

I: I wouldn't say that I use .... ehm, graphs very often but .... ehm, occasionally I do.

R: Okay in your opinion **'Do you think first-year biology students should be taught graphing skills if they seem to lack them?'**

I: Yes.

R: How should the skills be taught?

I: Ehmm, well they should definitely do them on a practical level, so, ehm, they should, perhaps, it should be a combination of a basic lecture outlining graphing skills and then some actual exercises where they can .... eh do graphs themselves based on some data sets that they are given or some examples that they are given, and if the classes are, eh, are small enough perhaps they could even make some graphs on .... on a computer.

R: So do you think using a computer would be a wise idea?

I: I do but I think ehm, it's problematic with the big first year classes. Ehm, and at that level I think it's fine just to teach them, ehm, to make graphs by hand. Because the basic principles are the same.

R: Okay. So by whom should the skills be taught?

I: I have no idea. Ehm, [Pause].

R: You think they should be taught at high school or when they get here at university?

I: Oh! [Pause]. I think .... I think probably just .... I mean at first-year, that's, that's probably sufficient. I ... I, to be honest I don't know anything about high school education to really be able to answer that question.

R: Okay. So **what do you do, if anything, about teaching these skills?**

I: Well, ehm, you see I'm satisfied with .... with the kind of system because .... ehm, the students that I lecture to have a practical that's devoted specifically to, to learning graphing skills. So, ehm, you know I am quite satisfied with the current setup. So when I lecture them it's not so much on "this is how you make a graph" but on using a graph to teach a concept.

R: Okay. So you don't specifically teach graphing skills?

I: No, no, no. We just use graphs to interpret data.

R: Okay. **Do you assess graphing skills in your course?**

I: Yes.

R: When do you assess the skills?

I: In tests and exams.

R: How do you assess the skills?

I: Well, ehm, we normally ask them to produce a graph, and, we specifically say what the graph needs to show, and we also ask them to label the 'x' and 'y' axes, and to show the units of measurement. So when we mark that, that exam question, ehm, the students get marked on how they label axes, whether they use the appropriate units of measurement, and, eh, the shape of the, the line graph that they're meant to depict .... that sort of thing.

R: But you didn't teach them that. You expect them to get this information from another lecture?

I: Yes.

R: Okay. So **do you have any test or exam papers for me to look at the questions?**

I: I can show you one.

R: Please do.

I: [Picks up a question paper from his desk]. This is their final exam, which the medics, the medical students just took about a week ago, ... and [paging through the question paper], there's a question for 5 marks, it says "Draw a graph illustrating a likely survivorship curve, identifying the type of survivorship curve, and clearly label both the *x* and *y* axis".

R: Can I have a copy of this.

I: Sure.

R: Okay generally do the questions on graphs count significantly in the tests or exams?

I: Ehm, I wouldn't say so. I wouldn't say they count a significant amount.

R: So the graphing skills is not an important section in your course?

I: No, no.

R: Okay then, thank you very much for your time...

I: Sure. Is that it?

R: ..... it was nice talking to you.

Interview 2: Staff member #2

I: Interviewee **R: Researcher**

Introductory statement: I am conducting a study for my MSc about the development and evaluation of a web-based computer programme on graphing skills for first-year university biology students. I am hoping that you could help me by responding to a few questions. I understand that you might be teaching at different levels, so I would like you to keep details of your answer at the first-year level. Also, if my questions are not clear, I would like you to tell me. You are free to elaborate on any matter that I might have left out, and you feel is important and relevant. I have also provided you with a pen and paper in case you want to write down some thoughts or ideas.

R: **What first-year course do you teach?**

I: Eh, I teach ILS ... which, eh, is “Introductory Life Sciences”, first-year eh. And it’s the physiology section. It is the ehm, animal and plant .... eh structure and function.

R: Okay. **In that course do you expect your students to use graphing skills?**

I: Yes.

R: Please explain what you expect them to do with graphs.

I: Okay firstly, eh, much of my teaching I use diagrams, eh, which I give out to students to illustrate my lectures. Everything, in other words, that ehm I project on the overhead projector, eh the students have in front of them. Many of these are in fact graphs, eh, and sometimes they are complicated graphs in the sense that more than one .... eh variable eh .... is being plotted on the same axes. In other words there is more than one graph, in fact, on a diagram. Ehm, I also require them to draw graphs, when I .... I give them some .... ehm, practical work .... eh practicals eh .... it’s physiology practicals eh I do these in front of the class, eh, it’s projected eh onto the overhead screen and eh, the data, ehm they tabulate from those experiments and they are expected then to draw their own graphs. Ehm I don’t have the time .... ehm since this comes towards the end .... ehm, I don’t .... well no, that’s not true. Eh I do not, eh, expect write-ups from the students, in other words I don’t, eh, check, eh any of their graphing ehm. This would be far too time consuming for me to handle on my own. I do the same thing ....eh, well this year I did the same thing with the first-year medics, eh .... which is the eh health sciences. These are three classes, the ILS that I mentioned earlier are two classes. Eh the medics or the health science students are three classes and I do the same experiments with them, and indeed I lecture the same material to them, also again using the same graphs.

R: **What graphing skills do you expect students to have when they enter first-year?**

I: I expect, eh first-year students, having got through matric, to be able to interpret a graph. In other words to eh, visualize how a particular variable, eh, changes with respect to another. Maybe it's badly put. But I expect them to see, eh .... to be able to interpret what the graph is telling them in terms of both of the axes, both the vertical and the horizontal axes. I would expect them to be able to read off exactly what changes are taking place, eh .... looking at both of those axes and the scales. Eh this is not, ... eh always .... eh, it has become clear to me that many students are unable to do that.

R: Do you expect them to be able to construct graphs?

I: Eh, yes indeed. Eh at the practical level, ehm, I eh .... They collect data, they tabulate the data and although .... frequently I don't have the time during the practical to allow them to actually draw all the graphs, I actually allow .... I insist they do the first one. But of course with these large classes I have no means of checking. Ehm, eh the, ... any subsequent graphs I expect them to do at home and I make it clear to them that this material is indeed examinable. So the onus is on them to understand the data, to graph it accurately, ... eh with my assistance of course I give them all the parame..., the ...the ...the, the data points for the graphing and they tabulate those data points and I expect them to actually draw the graph. Eh I generally point out that we have a dependent and an independent variable, eh. But I sometimes wonder whether all the students understand that concept.

R: **Which types of graphs do you expect your students to use in your course?**

I: Ehm..., all, ... anything that lends itself to graphing. Any change in a particular parameter with time, or eh.., eh ..., eh with anything else for that matter eh. Any change I expect them to be able to graph. In other words I expect them to be able to, eh .... interpret a eh, ... physiological result from an experiment for example, in ter.., or to depict it in terms of a graph and to interpret what that graph eh, actually means.

R: Do your graphs usually include line graphs?

I: Eh, what do you mean line graphs, they are all line graphs, ...oh you mean as opposed to histograms and so on?

R: Yes.

I: Ja. Mostly .... line graphs. I can't think of a single example of a histogram, eh during my teaching. Yeah, all line graphs.

R: What about pie, pie charts, and bar graphs?

I: No, no, no, I don't use those.

R: Okay.

I: I don't use those.

R: **In the first-year classes you have taught, do students seem to have graphing problems?**

I: Ehmm....., part of my problem is that (a) I don't have the opportunity or the time during a lecture course, ehm, to actually determine what the level of those skills actually are in the class. Ehm, I am aware that at the very beginning of the year, in ILS certainly, I don't know about the health sciences, but certainly ILS, they have an entire practical session at the beginning of the year devoted to graphing skills, and ehm, I make the assumption that all students understand, eh, the essence of graphing and of interpreting graphs. Eh but ehm, as I say, judging from, eh some of the questions, some of the problems students bring to me after the lectures, ... eh and so on, ... ehm, I, I [pause], eh..., I become aware that those graphing skills are certainly not universal. And it's a problem for me. Because as I say I don't have, ehm, very much time to specifically address those kinds of skills during my lectures.

R: **'Do you think first-year biology students should be taught graphing skills if they seem to lack them?'**

I: Yes indeed. I think it's very important. I think part of the problem .... is that many students, although they might have graphing skills, they might know how to draw given a set of data points eh, I think many students don't see the virtue of representing .... eh physiological, ... changes, ...as a graph. Eh, a graph tells you a great deal instantly, at a glance eh. And I don't think that many students appreciate the value of a graph in terms of the information that eh, can be depicted by a graph.

R: So in your opinion how should the skills be taught?

I: I think that ehm,.... Firstly I would assume that the majority, if not all of the students, know how to plot a graph, eh, given the two axes, eh, and the data points. Ehm, I, I'm guessing here but I would be very surprised if some students having gone through matric, do not have that basic skill. The kind of skill that I think that many students do not have, and it is something that we, I think should concentrate on perhaps, in, in putting across, very early, during the first, ... at the first-year level, is what graphs tell us. Eh, and the only way to do this I think, is to present students with an incredible variety of graphs, ehm, which I'm not convinced that they get, ehm, in that first graphing practical of theirs. A large variety of graphs and going from the very simple, right through to the very complex multi-graph diagrams, if I can put it that way, where there are many relationships being plotted simultaneously on the same axes, or indeed if there are for example, two different vertical axes and a graph showing, for example, eh, two graphs showing ...., two graphs showing two completely different .... eh parameters changing eh .... against a particular, eh, ehm, variable. And I think, ehm, you know, specific question need to be asked .... a graph presented, a particular graph presented to students in practicals or tutorials, and specific questions addressed to the students which forces them to interpret the information that is being depicted on those graphs. And I think this is where we need to be quite creative and to cover all the angles to make sure that the students do come away with the ability to interpret .... to look at the graph and say "Oh yes this is happening", eh.. over time, or whatever the case may be.

R: **By whom should the skills be taught?**

I: Eh, I think that you know, eh, who .... well, eh, I mean, at the moment in ILS it is done by the MCB department, the "Molecular and Cell Biology", because they simply happen to teach the first half of the year. Ehm, clearly it is a skill that needs to be in place very early on, to enable people like myself for example, who come later in the year to function eh you know, effectively ...., and to be able to make the assumption that these, ... all the students that I'm lect.... teaching, ... do have these skills of both graphing and of interpreting graphs. So definitely it should come early in the year. I think any academic, eh running such practicals ought to be competent to teach. I think, eh, a great deal of guidance, perhaps in the design of such a practical in the array of different graphs that are used, eh, on which questions are based, eh, for students to answer, eh I think perhaps, eh that some careful thought should go into these, and perhaps not every academic has the necessary experience with graphing to actually come up with such a wide variety of different graphs and so perhaps people like yourself in the education business, in the education field, eh ought to think perhaps of designing specifically one or more practicals or tutorials or whatever the case may be, that is designed to bring students from the very beginning assuming little or no prior knowledge, depending of course on the schooling background of a particular student. Eh, such a student might come to us with eh, considerable or virtually zero graphing skills. And so I think we need to start from the bottom and structure either practical, eh ...... protocols, exercises, or tutorials that is designed to bring everyone up to the same level of comprehension.

R: So at this moment **what do you do, if anything, about teaching these graphing skills?**

I: You know each graph that I present, ehm .... during the course of my teaching, I explain what the graph is actually showing, and I, you know implicit in that is my requirement that students understand this. And come exam time, come test time and it's clear to me that many students have actually not understood this, and so they are not viewing a graph the same way as I do, for example. And this tells me that they simply lack experience or exposure to be able to interpret at a glance what a particular graph is actually showing. Ehm, again, unless time is made specifically for teaching these kinds of skills it will always be implicitly rather than explicitly dealt with during any other kind of lecture course . So I think maybe, you know eh, a specific time ought to be scheduled early in the course. Eh, either at the lecture level, or preferably at the prac-tutorial level, where problems, eh, encountered by individual students can be recognised and addressed. At the lecture level with large classes, this is virtually impossible ..... to recognise problems in individual students. So I think, my, my suggestion is that we ought to make sure that whatever formal, eh instruction there is in graphing and graph-interpretation skills ....., I think this is an important distinction that I want to make. Eh, you may well be able to teach a student how to use a set of data to draw a graph but I think equally you need to teach the student how to interpret a graph. So these are two ...., I think ..... different skills that need to be focussed upon. And I think at the practical and the tutorial level, the right kind of instruction can be addressed at the individual level or at least, ehm, capable of recognizing and correcting problems of individual students, that they might be having. Impossible to do at the lecture level.

R: So in other words you don't specifically teach graphing skills?

I: No.

R: **Do you assess graphing skills in your course?**

I: Eh yes indeed I could easily do so but I don't make a point of it. Eh, I could for example, and have done on many occasions, provided graphs by way of being part of a multiple-choice question for example. And I can make such examples available to you if you want. I can go back in my files and pull out, I know I've used graphs on several occasions in the multiple-choice context where I ask questions on interpretation, ehm, and I could give some examples of that, ehm, so it would come up, you know, not eh, necessarily every year, but certainly I feel that it's something that can be assessed in an exam.

R: Would that be in tests or exams?

I: Both, either or. And it's an expectation that I would have of my students that certainly they would understand how to interpret the graphs that we have dealt with during the course of the lecture, ... of the lectures.

R: So usually do these questions, do these questions on graphs count significantly in the tests or exams?

I: Eh, well no, not necessarily. It would be a part of the exam or the test.

R: Can I have a look at those questions, when you have time?

I: Yes, I'll find them for you eh Dumisani in my, I have, I think I have files going back for many years and I can give you some examples of those. They may not be current ones, they may not be in eh, physiological topics that I cover these days, but it will serve to give you an example of how I use graphs in the assessment context.

R: Okay then. Thank you very much for your time, I enjoyed talking to you.

I: Good. So was that useful?

Interview 3: Staff member #3

I: Interviewee **R: Researcher**

Introductory statement: I am conducting a study for my MSc about the development and evaluation of a web-based computer programme on graphing skills for first-year university biology students. I am hoping that you could help me by responding to a few questions. I understand that you might be teaching at different levels, so I would like you to keep details of your answer at the first-year level. Also, if my questions are not clear, I would like you to tell me. You are free to elaborate on any matter that I might have left out, and you feel is important and relevant. I have also provided you with a pen and paper in case you want to write down some thoughts or ideas.

R: **What first-year course do you teach?**

I: Eh, I teach the physiology block on, ... for ILS. So that's the third block.

R: **In that course do you expect your students to use graphing skills?**

I: Yes, because a lot of the physiology stuff that I teach is most clearly explained using graphs. So I do, yes.

R: Can you please explain what you expect them to do with the graphs?

I: Okay, I use graphs mainly for interpretation of ideas. Okay so they, they may not necessarily have to collect data and graph it out or anything like that, but I expect them to be able to see a graph and explicitly interpret what that graph means, that what's on the y-axis is influenced by what's on the x-axis for example.

R: So you specifically stress constructing?

I: Not necessarily the construction, but, ja, I mean it is explicitly discussed what sort of structure the graph has, and what it means and the sort of stuff.

R: So **what graphing skills do you expect students to have when they enter first-year?**

I: I don't expect too much that's why I explicitly try and cover what is, eh, how to interpret them. And it's mainly the interpretation of graphs that I'm requesting ....., not the construction as you said.

R: **Which types of graphs do you expect your students to use in your course?**

I: Okay, we have things like regressions, line graphs eh, that sort of thing, things that will be covered in a spreadsheet under the title of scatter-plots. So it's really the ......, it's the linking of two factors, one that is dependent on the other.

R: What about pie graphs?

I: I don't use pie graphs.

R: Histograms?

I: Ehm, sometimes I do use histograms. I'm just trying to think of the first-year level, I don't think I use histograms at all. But certainly at the other levels, ... second and third-year level ...... I do start using those. And it's just because I don't need histograms to explain the work that I'm covering in first-year ...... that's the only reason. So ja I mean most of the physiological stuff that we're covering in first-year, are sort of line graphs, regressions, that sort of stuff.

R: Also no bar graphs?

I: No bar graphs.

R: **In the first-year classes you have taught, do students seem to have graphing problems?**

I: Ja, very clearly.

R: Can you describe the graphing problems they have that you picked up in your teaching?

I: They seem to have the inability to interpret what the graph is telling them. So for example if you've got a pair of axis with say temperature on the x-axis and metabolic rate on the y-axis, and you draw a line there and say "what does that graph tell you?" And the simple interpretation in this positive relationship here would be that as temperature increases the metabolic rate goes up, they can't tell me that. They, ... they have got no clue how to interpret that graph at all.

R: **'Do you think first-year biology students should be taught graphing skills if they seem to lack them?'**

I: Absolutely, because it's a necessary skill if you're going into science. But I think ..... that you know, as with statistics, the proper place to do that interpretation is when they need it. So if you get up to using a graph in a particular lecture you stop, you don't stop the lecture there, but you explicitly tell them how to interpret that graph, right in that lecture. I don't know so much if I would agree with having a separate section on how to interpret graphs, 'cause that's hell of a dry, ... it's not related to what they are trying to learn, you know. In the same way that statistical learning normally happens when the student needs the statistics for their own work they learn how to do that test. With the graphs I would sort of say the same thing.

R: So in your opinion how should the skills be taught?

I: Sort of at an *ad hoc* basis, whenever a new principle is needed in lectures, because of some explanation that is explicitly covered, and ..... so they ..... learn it bit by bit, in relation to the work that they are doing. So it's not just dry graphing skills. That would be the way that I would do it.

R: So you don't think there should be a special lecture or tutorial or practical on graphing skills?

I: I wouldn't be against it, it's just that my sort of style of teaching .... the way that I view it I would integrate it into the course. I wouldn't have a separate thing.

R: **What do you do, if anything, about teaching these skills?**

I: As I said, when we get, ... if I present a particular graph, I, I, ... especially at the start of the course, I'm very careful to explicitly go through and interpret the entire graph, not expecting them to be able to do that interpretation themselves. Okay, so I **use** the graph in my explanation . So if I'm, for example, ... ehh, the Bohr effect, that physiological fact with how blood transports oxygen. ...... I start the description of the Bohr effect by putting the graph up, and then I go and say okay now what is this line telling us. This is on this axis, this is on this axis, as this increases so what happens here and we do the interpretation. Okay. And by the end of the course, I mean I have the impression that they can understand the graphs better and I normally include some sort of graphing interpretative skill in the exam. It's normally **a** question that involves the graph.

R: So you don't have any particular strategy to teach graphing skills?

I: Well I would say that the way I'm doing it is a strategy, okay. And that is integrating it into the course. Okay I think that, in a lot of respects, as I've used the example of statistics, having a separate course on statistics and biology is, [pause] not that effective, because students don't relate it to the work that they are doing. And so, they learn the statistics in the statistics course, they get up to a point where they need stats for their own analysis and they got to go and relearn it for their own analysis. So it's almost like what's the point of doing the stand-alone thing.

R: **Do you assess graphing skills in your course?**

I: Ehm, I do, assess the skills that I explicitly try and tell them, that is it might only be interpretation. I'm not really doing construction. Not that I don't think that that's important, it's just that for my course, it's the interpretation of graphs that's important, and that's what I concentrate on.

R: When do you assess the skills?

I: In the tests and the exams. And then I mean, I often, I have an interaction in the class, the whole time. I ask people to do the interpretation for me and that sort of stuff, to try and sort of, peg the level.

R: **Do you have any test or exam papers for me to look at the questions?**

I: Not here I'm afraid but we could go and find some.

R: Okay, thank you very much for your time ......

I: Is that it?

R: Yes.

I: Sure! Okay.

Interview 4: Staff member #4

I: Interviewee **R: Researcher**

Introductory statement: I am conducting a study for my MSc about the development and evaluation of a web-based computer programme on graphing skills for first-year university biology students. I am hoping that you could help me by responding to a few questions. I understand that you might be teaching at different levels, so I would like you to keep details of your answer at the first-year level. Also, if my questions are not clear, I would like you to tell me. You are free to elaborate on any matter that I might have left out, and you feel is important and relevant. I have also provided you with a pen and paper in case you want to write down some thoughts or ideas.

I: So do you have to have my name on it, or what?

R: No.

I: Okay.

R: Firstly, **What first-year course do you teach?**

I: I'm a tutor, I'm not a lecturer, right? So what I do is, ... I'm in the ADP programme, that is the "Academic Development Programme", and I follow the students' lectures, and they are the students from the medical, eh, faculty. And ...... I make worksheets ...., and the worksheets are following a week of lectures. So they are after the week of lectures, right? And what I try to do ..... is to kind of give them basic information, because that programme is for students that are coming from township schools, or that haven't done biology for their matric. And others are free to come too, but my idea is to help them, especially those students that are weak, to help them understand the basic concepts.

R: **In that course do you expect your students to use graphing skills?**

I: Yes, they have to. There's a pool of graphing skills.

R: Can you please explain what you expect them to do with the graphs?

I: To understand them. [laughs]. I have put together here a lot of examples, ... you know, of graphs, different types of graphs that they encounter. In their pracs and in their lectures, and in their exams.

R: So **what graphing skills do you expect students to have when they enter first-year?**

I: Eh very simple ones, like ..... eh, you know with an ‘x’ and a ‘y’ axis and the different points that are found in an experiment, that they are able to say what is happening during the experiment. So, very simple ones just with two axes.

R: Do you expect them to be able to read and interpret graphs?

I: Yes, yes.

R: Do you also expect them to be able to construct graphs?

I: Yes, that’s true.

R: **Which types of graphs do you expect your students to use in your course?**

I: I’m not sure what types of graphs do you, do you distinguish.

R: Do you expect them to use line graphs for instance?

I: Yes.

R: Which other types of graphs, other than line graphs?

I: Some, eh, graphs in biology very often goes with what happens in the cell or what happens in the body, eh, with enzymes for example. They go consecutive, so you get a picture of what happens in the cell, then you get a graph and the time axis is the same as the time axis in the picture for example. So they have to understand how that corresponds, right. And others for example, a very complicated one where you have the heart beat for example, right. The systole and diastole and the heart beat is on the time scale...

R: Can you repeat those words again?

I: The systole and diastole, that is the contracting and the relaxing of the heart, yeah? So you get ehm, you get a graph of pressure over time, differences in pressure of the two components of the heart, the atrium and the ventricle. The atrium gives a lower pressure when it contracts than the ventricle. And so they have to be able to tell what happens in the atrium and what happens in the ventricle with regard to the pressure which is, eh, ehm, which is made when they contract, right? And then they have to, for example, know something about the volume of the heart, that the right side and the left side has the same volume but different pressures. So it’s very complicated diagrams of, eh graphs that they have to understand.

R: Do those usually include pie charts?

I: No, no. No pie charts.

R: Histograms?

I: Ehh, no, not histograms, it’s line graphs.

R: Just line graphs?

I: Mainly, not only. But you know you have for example histograms when you do something about populations,

R: Okay.

I: Then you get histograms, you know. But eh, not very often. What we deal with is mainly eh ...., like electrical kind of circuits, what’s eh, it’s a model of what happens in the different organs, right?

R: **In the first-year classes you have taught, do students seem to have graphing problems?**

I: Yes they have.

R: Can you describe the graphing problems that you have picked up in your teaching?

I: Ehm, in the beginning they forget to read, for example the, ehm, coordinates, to see what does the x-axis represent and what does the y-axis represent. And sometimes the y-axis is more just like one single thing like eh, temperature or eh, pressure. So often it is a ratio, right? Then they cannot figure out what is the ratio, for example. It is, you know, like we said temperature over time. And then you have the x-axis of what happens to an enzyme, for example what happens to a substrate. And, eh, another one is a, another problem is when they have two y-axes and one x-axis. They forget to read one, so they don't understand what is happening in the graph. So you really have to explain that. Once they get it, they are fine. But they don't understand it .... you really have to explain it. Especially students that come from township schools. Students that are black and white that come from private schools don't have so much problem with that.

R: So in other words the problems are mainly on interpretation?

I: Yes. And also put it together. You know when you tell them for example to make a graph, for example here you have information of an experiment, and they have to put that on graph paper, they don't know whether to connect the points with straight lines or with ehm ...., eh, how do you call it, a bent line? I'm not sure [laughs], but not a straight line, you see sometimes ....

R: Like a curve?

I: A curve, that's right, they don't know whether to make a curve or not. They don't know what extrapolating means. Ehm, sometimes with extrapolating they have to understand that it doesn't always draw in the line of the curve, it has to flatten out and as a graph or when the enzyme is all occupied then it has to go flat, or when enzyme just denature for example, at high temperature, that the graph goes down because all the enzymes are dead. So these things they have to really learn.

R: **'Do you think first-year biology students should be taught graphing skills if they seem to lack them?'**

I: Ehm, that depends. I think the first-year biology students in medical schoo,l when they come from private schools, or eh, the C, eh, what do you call this, eh schools, government, the C-type schools.

R: Okay.

I: Ja, they, they are quite used to graphs and they have a good foundation. But when they come from the, eh, from the township schools, and they lack that foundation they, don't really know what to do. But I think they do get graphing at physics and chemistry and in maths, so that all together kind of pulls it together, and helps them to understand graphs.

R: So you don't think there should be a specific lecture or tutorial on graphing skills?

I: There is, there is in the prac. They have a whole prac on graphics, graphing skills. Medical and, eh for example, most of them are not, eh, familiar with the log graphs. You know, the log paper and the different, eh, dimensions?

R: Yes.

I: So that is very confusing for them, so we have built in, in the pracs, graphing skills.

R: So in your opinion how should the skills be taught so that, they can understand them better?

I: I think just from simple to, you know very, eh, complex, ehm, ehm, oh yeah ...[pause]. In biology ehm, it is mainly kind of applied. It is not theoretical, it is applied. It, it's, it grows out, you, what do you observe and how do you summarize that in a graph, and I think that is what a ba..., is a basic concept in the graphing skills. That they understand what they see and how to kind of picture that in a graph.

R: So who should teach them the graphing skills?

I: Ehm, I think lec..., the eh, I think in a prac it is fine, but not only in the prac, yeah? But I think in tutorials it would be a good addition to those students who lack these skills. You know they need to be helped. If you don't help them in the beginning, they are really struggling throughout the year because they don't know how to read a graph and how to construct a graph.

R: So **What do you do, if anything, about teaching these skills?**

I: Ehm, I use a lot, eh with overheads, and when I teach, then I emphasise always which axes there are, or I ask them which axes there are, what are the parameters, you know what do you write in this axis. Ehm, what is the line ...... the graph mean, right? Ehm, what, how is it compiled, which sections can you find in the graph. So they get an idea they are going to link, associate with events, events with the, with the abstract ideas of a summary in a graph.

R: So when you say you ask them, do you specifically teach graphing skills or you expect them to have them?

I: Ehm, [pause], I teach when I see that they don't understand.

R: Do you use any particular strategy to teach graphing skills, when you see that they don't understand?

I: Ehm, no, not a conscious one, I just go, I, I try to see what they know, and I go from there.

R: **Do you assess graphing skills in your course?**

I: They, they get graphs, different types of graphs in the, in the exam for example. Here, this is an exam [showing a question paper]. That is eh, that are two different graphs, okay. Here they have to make a graph. There they are asking a question about log graphs, what do they mean or which one represent, eh, log 3 cycle by log 4 cycle. They are trying to find whether they understand these different graph papers. How to represent these things and when to use them. When you have a log graph, for example, then you get, you need a huge paper to kind of put on the same thing, log 10 or log 20 or 2 log 10 or 5 log 10 or, if you put it in normal numbers you just kind of, you can't put it on a normal graph, that's why they must understand that, that is a log graph. So that when dealing with large numbers they have to represent it in another way.

R: This looks complicated even for me, do they manage to understand this?

I: They do, but it is very difficult.

R: It's difficult.

I: Yeah, they have to, to understand this because very often you are, working with ehm, with eh, small amounts but micrometers, microlitres, yeah? But you have to eh, you have a great range, so you have to use log graphs to be able to, to depict it on a paper.

R: Do you have more of these question papers?

I: Ja I have I have here also graphs that is what I used in the, in the lectures. I can, you know I can lend them to you if you are interested to look at them.

R: Yes.

I: And make photocopy. Like this one that is about the eh, endocrine system and that is about the, hormone eh ......, concentration and what happens in the ovaries when, are these hormones, these different hormones secreted, what is their concentration and so forth. So they have to understand that these ones, you know communicate with one another.

R: With your permission I would love to look at them.

I: Yes, oh that's fine I have just put, this book is full of it. Physiology is almost all graphs.

R: Okay.

I: Yeah, and then here I have indicated some of these questions that I help them with. You know here about a heart, here you have a graph, right? And how they interpret, have to interpret what happens, for example, in the lungs, what happens in the tissues, all these things. You know and here a graph about velocity and in this book you will find graphs about velocity of the blood, pressure of the blood and, ehm, concentration of oxygen, concentration of carbon dioxide as it flows through the body, right. So it's very complicated graphs they have to understand. So I looked for it yesterday and here, these that are yellow, that are the questions and green are the answers. That is a teacher's guide. This one is out of print, right? So ...... but I have indicated where you can find graphs [laughs].

R: Okay then, thank you so much for your time ......

I: Is that all?

R: .....you've helped me a lot.

I: Okay.

Interview 5: Staff member #5

I: Interviewee **R: Researcher**

Introductory statement: I am conducting a study for my MSc about the development and evaluation of a web-based computer programme on graphing skills for first-year university biology students. I am hoping that you could help me by responding to a few questions. I understand that you might be teaching at different levels, so I would like you to keep details of your answer at the first-year level. Also, if my questions are not clear, I would like you to tell me. You are free to elaborate on any matter that I might have left out, and you feel is important and relevant. I have also provided you with a pen and paper in case you want to write down some thoughts or ideas.

R: **What first-year course do you teach?**

I: I teach the 'College of Science'. That's the Biol122 and 123 courses.

R: **In that course do you expect your students to use graphing skills?**

I: Yes.

R: Please explain what you expect them to do with graphs?

I: Okay they have to know how to draw graphs. So we might give them, ehm, a table of data and they have to use that data to actually draw up the appropriate type of graph. Ehm, we also expect them to be able to interpret graphs. So it might be to interpret a graph that they have drawn up, say in a prac situation, where they have done an experiment and they have recorded the data, eh, they've drawn the graph and they have to interpret it. Alternatively we also, ehm, give them activities in tuts, and also tests and exam questions where we give them graphs. And they are then required to interpret the graphs. So in a sense it's all aspects of graphing.

R: **What graphing skills do you expect students to have when they enter first-year?**

I: We don't exp... we, it would be nice if they had, but we don't expect them to have any. So we assume that we are actually starting from the beginning, in terms of graphing.

R: Okay. So **which types of graphs do you expect your students to use in your course?**

I: Ehm, we expose them to a variety of different kinds of, of graphs, ehm. For instance in, in the second year of the college, okay now I'm talking of first and second-year college but they are equivalent to first-year, both of those courses are equivalent to first-year.

R: Okay.

I: Okay. So I'm gonna talk about both of them, because we teach some of the skills to the college first-year group but some of the skills to the college second-year group. Okay? But essentially they're still first-year students.

R: Okay.

I: It's just that so that you're clear on that.

R: Okay.

I: Okay? Ehm, ... For instance, with our second-year group, we have a tutorial ...... specifically, it's called "working with data", and that focusses on graphs and different types of graphs. And there ...... and then they have tut exercises where they have to either draw up or interpret graphs. And so we introduce them to line graphs and bar graphs, ehm of various kinds, and pie charts. Those are the main ones.

R: You don't do histograms?

I: And histograms, yes.

R: Okay. **In the first-year classes you have taught, do students seem to have graphing problems?**

I: Ehm, ... yes. They, ... do you want me to tell you what sorts of problems?

R: Yes, can you describe ......

I: Yeah, okay. The sorts of problems they have are things like identifying which variable should be plotted on which axis. In other words if you give them a set of data they often have problems deciding which is the independent variable and which is the dependent variable. Ehm, so that's one aspect ...... that's a problem with graphing. Ehm, they ...... also have, ... they sometime have problems interpreting graphs. And I don't know if this is ...... partly a, ... ehm, an issue of their inability to express their interpretation, or if it's more a lack of ability to interpret. Because if, say, for instance you set an exam question, where we give them a graph to interpret. Ehm. What we teach them to do is to, is that interpretation has two components. It's a quantitative description of what's in the graph, and then it's an explanation of that. So in other words it's first saying what's happening in terms of the numbers or the values of the trends, and then that's the part of the description, and the explanation is then relating it to the theory. Okay, so the seed has died because it hasn't had oxygen, so that's the biology. Okay, and then, ehm, they tend to often battle with the quantitative description because they just look at the graph and they say "Oh the line goes up and the line comes down", rather than actually saying, you know from day one to day six there was a ten percent increase in whatever, that's ultimately what you're trying to get them to do. They tend for some reason to resist that. And I don't know if it's just a maturity issue that, you know later on in their undergraduate studies they cotton on to, ... to that aspect and start bringing it in. But we certainly do try and teach that and encourage them to do that. Ehh, another thing, so that's, the yeah. Other problems with actually drawing up graphs are often just carelessness in terms of not plotting points accurately. But sometimes they also battle to work out an appropriate scale for the graph. Ehm, you know they kind of don't plan ahead, or think ahead in terms of .... particularly drawing up the, the, the..., vertical axis. You know, they either have a scale that is very expanded, or a scale that is too contracted. Then either way it actually influences the shape of the graph and of course it influences their interpretation. So that's also something that they, they sometimes tend to battle with. Ehm, you know we're quite particular in terms of our, our, you know when we mark a graph, if the students have had to, say in a test draw up a graph. We will allocate marks for, eh the accuracy of the plotting of the points and also the labelling of the axes, you know. Have they given what the axis is and the unit of, of that? Have they given the graph an appropriate title or legend? Is it written below the graph? So we're quite particular in terms of eh, ... you know the, the things that we look for, and that we award marks for. And sometimes they are a bit careless in not actually labelling the axes, and that sort of thing. But I think that's not really a conceptual problem, it's more just learning ...... what's required when you do a graph.

R: So would it be safe for me to conclude that they have both, they have problems both in constructing and interpreting graphs?

I: Mhm [nodding the head].

R: **'Do you think first-year biology students should be taught graphing skills if they seem to lack them?'**

I: Should they be taught them?

R: Mhm.

I: Definitely.

R: How should the skills be taught?

I: Ehm, [pause]. I think .... various ways. I mean, what we do in the college is, ... they are taught the skills through tutorials. But then they are given plenty of opportunities to actually apply those skills and, for them to be assessed and to get feedback on that. Because for instance in the block where we actually, in the second-year ..... where we focus on teaching particular aspects of graphing, they have a self study project that they do, where they have to do a little experiment on plants and then they have data so they are required to draw up their own graphs and interpret those. They would give ...... they get marks for that. And then in tests and exam situations we always give them graphs to either construct .... and, ... or we give them a graph and ask them to interpret it. So I think it's a combination of actually teaching the skills in an environment where the students feel safe to practice the skills and get, ... you know immediate feedback on what they are doing .... but then also to give them plenty of other opportunities to apply the skills and to get feedback on, ... on how they are doing in terms of their graphing.

R: So in your opinion is it the university responsibility to teach the graphs or they should be taught them at high school?

I: [Long pause] Ehm, [pause] I think that the students coming in essentially to do a science degree need to know about graphing because it's an essential part of any, ... any aspect of the sciences, ehm, ... because graphs are such an important way of actually communicating information. And I think that it probably needs to be taught both in the school and, ... and here. I think what we do is we, ... it would be good if students came in with that knowledge and all we were doing was reinforcing it or putting it in a particular subject context. But I think that we can't assume that, and we have a responsibility, if we want the students to know how to graph or to use graphs, we need to teach them that.

R: So **what do you do, if anything, about teaching these skills?**

I: Well we have, as I've said we have, ehm, tutorials specifically set aside for teaching students, focussing on these particular skills, ja. And then, as I said, we also then give them opportunities through project work and tests and exam - formal assessment, where they need to put those skills into practice and they get feedback on how well they are doing.

R: So in other words you, [pause] okay do you use any particular strategy to teach graph construction?

I: What do you mean by a particular strategy?

R: Like you have, you have certain lessons that are specifically concerned with graphs or with constructing graphs, and you make sure that they are capable of constructing graphs before you give them .....

I: Yah, that's what I was saying we have specific tutorials, that are set aside and focus on graphing.

R: Both constructing and interpreting?

I: Yes. And then they have, ... so the first part of .... so it's a two hour tutorial. The first part of the tutorial would be, ehm, working through ..... sort of various aspects of graphing ..... definitions like, what's the dependent what's the independent variable and so on. And then we go on to looking at graphs and what variable goes onto which axis and what type of graph should you use for what type of data, ... so in other words what's appropriate for, ... what sort of data you would use for a line graph, what sort of data for a bar graph, and so on. So that would, say, form the first part of the tutorial. And the second part would be the students working, ehm, ... through a set of exercises ...... that are designed to then, ehm, ... test whether or not they can apply what you've covered in the first part. So that involves interpretation and also constructing graphs, ... and you know, working ..., looking at a set of data and saying well that's the dependent, that's the independent, and so on. In other words, ... you know each exercise is not about drawing a graph, but it's about different aspects that ultimately will lead to students drawing an appropriate graph.

R: And then you want to tell me that at the end of all that you still have problems, because that sounds very thorough. They still have problems?

I: You see the thing is it's, it's, it's like any learning experience, we can only take the students that far, but each student actually has to sit down and think through it for themselves. And those who do, are fine, but those who never actually sit down and think through for themselves "now I've got to, have got to come to grips with what is an independent variable for myself, I have got to come to grips with what is a dependent variable for myself". They battle.

R: **Do you assess graphing skills in your course?**

I: Yes, ja. Through assignments and through, in their practicals, if they have experiment type, experimental pracs, they often have to plot graphs of the data, so that, they .... and then those will be marked. Eh, and then also in tests and exams we assess graphs.

R: Do you have tests or exam papers for me to look at the questions?

I: Ja.

R: Can I borrow some, I'll photocopy them and return them.

I: Yeah, sure.

R: Thank you very much for your time, that was all.

I: Is that all?

R: Yes.

I: Okay.

Interview 6: Teaching assistant #1

I: Interviewee **R: Researcher**

Introductory statement: I am conducting a study for my MSc about the development and evaluation of a web-based computer programme on graphing skills for first-year university biology students. I am hoping that you could help me by responding to a few questions. I understand that you might be teaching at different levels, so I would like you to keep details of your answer at the first-year level. Also, if my questions are not clear, I would like you to tell me. You are free to elaborate on any matter that I might have left out, and you feel is important and relevant. I have also provided you with a pen and paper in case you want to write down some thoughts or ideas.

R: **What first-year course do you assist in?**

I: I help with the medics, ... that's the biology class.

R: **In that are the students expected to use graphing skills?**

I: Yes.

R: Can you please explain what they are expected to do with graphs?

I: Eh just basically to represent data that they would have collected in the lab, eh ..... on experiments that were done, like respiratory experiments ..... just to plot, ... to see different trends in their data they collected.

R: **What graphing skills do you expect the students to have when they enter first-year?**

I: I expect them to basically know what a graph is, and to basically understand what a graph is supposed to represent. Some of them do battle to understand you know, what goes on the x- and y- axis. But that comes with learning it in the first-year level.

R: Do you expect them to be able to interpret graphs?

I: Yes.

R: Do you also expect them to be able to construct graphs?

I: Yes.

R: **Which types of graphs do you expect your students to use in that course?**

I: Eh, linear graphs and histograms.

R: What about line graph?

I: Yeah, linear graphs are line graphs.

R: Linear graphs are line graphs?

I: Ja.

R: Okay. What other types other than those two? What about pie graphs and histograms?

I: Eh. Ja they do pie graphs, and also the first-year medics learn to do linear, tch ..... log graphs.

R: Log graphs?

I: Ja.

R: No histograms and bar graphs?

I: Ja they also do do histograms too?

R: And bar graphs?

I: And bar graphs.

R: Okay. **In the first-year classes that you have assisted in, do students seem to have graphing problems?**

I: Yes they do.

R: Can you describe the graphing problems they have that you have picked up in your teaching?

I: Ehm, the graphing problems they have ..... they don't know whether, because eh in first-year ..... I think they expect them to know kind of where ....., to be able to construct their own graphs instead of being told, you know, this is on the x-axis this is on the y-axis, they expect them to know which is, ... which is which, you know, to know which is the dependent and independent variable, and they don't know how to do that, so they battle with that they often get the axes the wrong way around. Ehm, they often battle to determine the scale and what they need to do, eh, so, sometimes if the scale ranges from, from 5 to 100 then they don't know how to plot the 5 to 100, you know, and they don't know what to do with the zero, whether they should have a zero at the bottom of the y-axis or the x-axis, ... they don't know that you can have broken graphs.

R: So that's basically on constructing graphs?

I: Yes, constructing graphs.

R: What about interpreting graphs?

I: Ehm, I haven't really seen problems with interpreting graphs. They seem to able to do that.

R: So in your opinion **Do you think first-year biology students should be taught graphing skills if they seem to lack them?**

I: Yes. I do think they should be, ... they should be taught graphing skills, because they are a very important aspect of biology.

R: So how should the skills be taught?

I: Well in the first-year, the first-year medics that I do, there's a whole lab on just graphing skills, which they try to teach them independent variables and dependent variables, and how to, ... the scales, and that they can have broken graphs and what trends graphs try to show them. So I think that's a very good lab. So even with that lab they still battle. They battle with where to put the heading, also dependent and independent variables.

R: So do you think more should be done?

I: Ehm, not necessarily. I just think some of the students just go into the labs and they want to get out of there as soon as possible, so they don't really want to learn it. It's just a matter of applying their knowledge and actually taking the time to learn it. That's where the problem, I think, lies.

R: By whom should the skills be taught?

I: Ehm, I definitely think by their tutors in the lab and also their lecturers. And then by themselves too, they also must need to want to know how to do it.

R: So you as TA's, **What do you do, if anything, about teaching these skills?**

I: Ehm, we answer their questions. And then we mark their lab reports, and if they've done it wrongly then we ..... we would show them where they've done it wrong. And each time they have a graph, ehm ...., they do in labs that follow, and they've done them wrong, we then explain to them again why they've done it wrong and how they've done it wrong.

R: Are there any special measures that you undertake to improve the students' graphing skills?

I: I can't think of any other than just trying to help them with ..... in that lab. That's basically the only time they really get the chance to, ... well where we sit down and show them how to do graphs. Other than that, in the next lab ..... they're expected to know how to do that. They're expected, ... the lecturers and, ... expect them to know how to do graphs, now, after that. And sometimes they battle. Maybe the lab, that lab needs to run over two days, I don't know.

R: **Do you assess graphing skills in the course?**

I: Yes.

R: When do you assess the skills?

I: During that lab that I was just telling you about.

R: Okay. How do you assess the skills?

I: Eh, by just marking them and giving them a mark out of whatever the mark for that.......

R: So you don't have any test or exam papers for me to look at the questions?

I: I don't know, I wouldn't have the, ... the exams or test papers.

R: The lecturer has them?

I: Ja. I'm sure, ... like in the lab ..... their prac test, they might be asked. They're definitely asked like to draw graphs and to interpret graphs which they would be expected to have learned from that lab that people have done, on graphs.

R: So would you have any suggestions for me which lecturers I could ask for question papers?

I: Ehm, maybe ask eh, Stuart Sims, because he coordinates the medics.

R: Stuart Sims.

I: Ja, Dr Stuart Sims.

R: Okay.

I: Upstairs.

R: Okay.

I: Cause he does, he interprets, he is the coordinator, for the medics.

R: Okay. Thank you very much for your time, that was all.

I: Is that it?

R: Yes.

Interview 7: Teaching assistant #2

I: Interviewee **R: Researcher**

Introductory statement: I am conducting a study for my MSc about the development and evaluation of a web-based computer programme on graphing skills for first-year university biology students. I am hoping that you could help me by responding to a few questions. I understand that you might be teaching at different levels, so I would like you to keep details of your answer at the first-year level. Also, if my questions are not clear, I would like you to tell me. You are free to elaborate on any matter that I might have left out, which you feel might be important or relevant. I have also provided you with a pen and paper in case you want to write down some thoughts or ideas.

R: **What first-year course do you teach?**

I: Ehm, I help out in the medics pracs, and ILS pracs.

R: ILS?

I: Ja.

R: **In that course do you expect your students to use graphing skills?**

I: Yes.

R: Can you explain what you expect them to do with graphs?

I: Ehm, in the ILS course, for Ed, they have to take a whole heap of, ehm ....., plant data, and plant distribution data, and then graph the three different plots to compare changes in the vegetation in three different areas. And the medics, I didn't do that particular prac with them this year but I think they did ehm, different kinds of, you know different types of data and then the way you would graph different types of data.

R: **What graphing skills do you expect students to have when they enter first-year?**

I: Well I would think that they should be able to read, ehm ...., different, ... say tables of results and transfer those results onto a very simple graph.

R: Okay. Then do you also expect them to be able to construct graphs?

I: Yes.

R: **Which types of graphs do you expect your students to use in your course?**

I: Ehm, what kind? .... I mean they should be able to do an ordinary simple graph. One of those kinds ....

R: Line graph?

I: Line graph. And also ehm ...., what are those ...., bar graphs?

R: Okay, bar graphs?

I: And, possibly pie charts, but maybe not. I don't know if they've ever done pie charts at school, and I don't know if that comes under graphing skills.

R: Yes it does.

I: It does?

R: Yes.

I: Ehm, but I'm not sure if they've ever done that at school. So ehm ...., but certainly the first two.

R: What about histograms?

I: Does that not rate as a histogram, a bar graph?

R: No there's a slight difference.

I: Oh! No I didn't even know there's a difference.

R: Okay.

I: So what's a histogram?

R: I'll tell you later.

[Both laugh]

R: **In the first-year classes you have taught, do students seem to have graphing problems?**

I: Yes.

R: Can you describe the graphing problems that you have picked up in your teaching?

I: They battle, some of them, to know what should go on the x-axis and what should go on the y-axis. Ehm they also have problems with telling continuous data, that would possibly go on a line graph, from discontinuous data that would go either on a bar graph or on a histogram or something like that.

R: So that's basically, they have problems with constructing graphs?

I: Yes.

R: What about interpreting graphs?

I: Ehm, yes, definitely. Well, specifically, I mean, you know if they constructed a graph, say of oxygen consumption, and then you give them a whole set of different figures and ask them to read off that graph that they've drawn, some of them do battle.

R: Even if they drew the graph themselves?

I: Yes. I think so.

R: **'Do you think first-year biology students should be taught graphing skills if they seem to lack them?'**

I: Yes.

R: By whom should the skills be taught?

I: I suppose that it could be better to be taught, ... well both, maybe in a lecturer and, in a lecture and in a, in a, and in a prac situation.

R: How should the skills be taught?

I: I haven't a clue. I really don't know. Eh, no. I don't know enough about it to know how they should be taught.

R: Okay.

I: But definitely with some kind of hands-on system, you know theory and practical, I'm sure. But other than that I can't add.

R: For you, **What do you do, if anything, about teaching these skills?**

I: Well, try to help where I can, but, you know sometimes [long pause], ... You, ... well, about the only way I can ..... input I think ..... is to, ... when you're marking their practicals, to mark quite carefully and to put comments on where they're wrong and why they're wrong. But for the rest, I don't really, you know, do much of it at all.

R: So you don't have any particular strategy of teaching graphing skills?

I: No.

R: **Do you assess graphing skills in your course?**

I: In the medics classes they do, but as I say I didn't do that prac this year. I was away. So I'm not completely sure. Ehm, in the ILS course, not really [pause]. You know it's part of a prac write up, where they produce and hand in a report at the end of a series of three pracs. So the graphing skills aren't taught to them particularly. It's something that, it's assumed that they know, and that they will produce in that report. The medics actually have a full-on one prac of three hours doing a full-on graphing prac, with different kinds of graphs, different kinds of information. Ehm, so they have a much more intense, ... you know they are actually taught graphing, whereas the ILS course, the bits that I did of it anyway, the animal and plant side, didn't. They're just assumed that they would know ..... what to do.

R: Okay. Thank you very much for your time, that was all.

I: Is that it?

R: Yes.

I: I doubt if that was much help.

R: It was.

Interview 8: Teaching assistant #3

I: Interviewee **R: Researcher**

Introductory statement: I am conducting a study for my MSc about the development and evaluation of a web-based computer programme on graphing skills for first-year university biology students. I am hoping that you could help me by responding to a few questions. I understand that you might be teaching at different levels, so I would like you to keep details of your answer at the first-year level. Also, if my questions are not clear, I would like you to tell me. You are free to elaborate on any matter that I might have left out, and you feel is important and relevant. I have also provided you with a pen and paper in case you want to write down some thoughts or ideas.

R: So, **What first-year course do you assist in?**

I: First-year "Health Sciences"

R: Health sciences?

I: Ja.

R: So **In that course do you expect your students to use graphing skills?**

I: Yes.

R: Can you please explain what you expect them to do with the graphs?

I: It's just very simple graphs where ehm, they conduct simple experiments, and then they have to graph their results. Ehm, and it's not, it's nothing very elaborate, but they do need to know how to do it.

R: **What graphing skills do you expect students to have when they enter first-year?**

I: When they enter first-year? Well, we do give them quite a comprehensive little, ... eh, ... okay tut almost .....

on how to ...., and in their lab book they've got notes on how to do graphs and set up graphs. So we don't really expect them to know too much when they first come in, because we do teach them. It's part of the course.

R: So do you expect them to able to read and interpret graphs?

I: Ehm, by the time they, ... that we've taught them, yes. But not necessarily when they come in.

R: Okay. Same for constructing graphs?

I: Yes, ja. I mean obviously it helps if they have a little bit of knowledge and they have looked at a graph before and they know, ... they have seen it before, but we don't expect them to, ... to immediately know how to draw up a graph.

R: **Which types of graphs do you expect your students to use in the course?**

I: They use ehm, ... well during the sort of graphing course where we teach them, they use line graphs, bar graphs, pie charts, and ..., ja, that's about, ... those are the main ones.

R: And also histograms?

I: Ja, and histograms, ja.

R: **In the first-year classes that you have assisted in, do students seem to have graphing problems?**

I: Ja they do, actually. They tend to, ehm, ... struggle with some things.

R: Can you describe a bit more on the graphing problems that you have picked up in your teaching?

I: Ehm, it's really like the little details, like the ehm, ... the layout of the graph. So they, ... they often forget to label axes. They ehm, they don't always read it off the axis properly, so the actual points are some times wrong, ehm, when they're plotting it, especially with the line graph. Ehm. They don't always label it clearly ....., like they forget ..... they leave out the units, ehm, that kind of thing. So they ..... you don't always know what the graph is about. Oh, also the headings aren't very descriptive, so they need to, we try and encourage them to give more details.

R: Okay. **Do you think first-year biology students should be taught graphing skills if they seem to lack them?**

I: Definitely, ja.

R: How should the skills be taught?

I: Ehm, I think in a practical kind of way like, eh, ... like we do it in the labs. If they have just a short tut before hand, giving the theory behind it and just telling them how to go about it, then I think the best way for them to learn is just to be given data and actually plot it. And then if you have a demonstrator or someone going round and just checking ..... that they're doing it right, then they can pick up the mistakes straight away.

R: By whom should the skills be taught?

I: By whom, ehm, I don't know I guess whoever is, eh, coordinating the first-year labs and then the demonstrators, obviously.

R: So for you, **what do you do, if anything, about teaching these skills?**

I: Eh well, as I said it's built into their particular course, and then they have to hand in that prac at the end of the week and then we mark it and so they, ehm, from the marking they can see where they're going wrong. Like, they're given data and they have to .... like plot it.

R: Do you use any particular strategy for teaching graphing skills?

I: Ehh, no. Its just ..... its just really practical. They're like given a set of data, and they're asked questions, ehm, ... on how they would go about graphing it and, ehm, ... then they have to draw up a graph, and then we check that it is correct.

R: **Do you assess graphing skills?**

I: Yes, ja.

R: When do you assess the skills?

I: Ehm, normally eh, ... when they, ... when we're teaching them. At the end of that particular practical we all mark it. And then also like throughout the year, whenever they have to plot data then we all mark the graph, that kind of thing.

R: **Do you have any test or exam papers for me to look at the questions?**

I: Sure, ehm, possibly. I can have a look at my, ... you mean like eh, ... I only have the practicals, not a test or anything.

R: Okay, even those will be okay.

I: Is it? Okay, ja, I can get those.

R: Please do.

I: Do you wanna see them now?

R: Ja, because we are almost finished.

I: Oh, oh okay.

R: Thank you very much for your time.

Interview 9: Teaching assistant #4

I: Interviewee R: Researcher

Introductory statement: I am conducting a study for my MSc about the development and evaluation of a web-based computer programme on graphing skills for first-year university biology students. I am hoping that you could help me by responding to a few questions. I understand that you might be teaching at different levels, so I would like you to keep details of your answer at the first-year level. Also, if my questions are not clear, I would like you to tell me. You are free to elaborate on any matter that I might have left out, and you feel is important and relevant. I have also provided you with a pen and paper in case you want to write down some thoughts or ideas.

R: So, **What first-year course do you assist in?**

I: Medics and College of Science, occasionally. And CLS, um....., CLS.

R: CLS? Not ILS?

I: Yes, CLS.

R: **In those course do you expect your students to use graphing skills?**

I: Yes.

R: Can you please explain what you expect them to do with the graphs?

I: Eh, well mainly medics. They'll go to graphing, tutori.., eh graphing prac, and that's when they get taught how to use all the different graphs. And then they do do experiments on how to graph the results of the experiments. Ja. Eh CLS also have to do that. ILS have ..... College they have never had to draw a graph when I have demonstrated.

R: **What graphing skills do you expect students to have when they enter first-year?**

I: They should be able to read a graph and know how to get information off a graph, and how to draw the graph, and what kind of graph to draw.

R: So, **Which types of graphs do you expect your students to use in the course?**

I: Mostly they use bar graphs or line graphs. Occasionally pie charts, but not that often.

R: What about histograms?

I: And histograms.

R: **In the first-year classes that you have assisted in, do students seem to have graphing problems?**

I: Some of them do, some understand straight away, but some really battle and don't understand and don't know what they are doing, even what a dependent and independent variable is .... what to graph, on which axis, and stuff like that.

R: Can you explain more the graphing problems that you have picked up in your teaching?

I: They don't know what to put on what axis, and they don't know what kind of graph to draw when. So they'll try to draw ..... a line graph when they should be drawing a bar graph or histogram, or they've got the axes the wrong way round or ..... something like that.

R: So that's basically with constructing graphs?

I: Ja.

R: What about interpretation, do they have problems?

I: They generally don't, because most of the interpretation they do is off line graphs and they just draw the lines and they can read straight off, but the interpretation doesn't seem to be a problem.

R: **Do you think first-year biology students should be taught graphing skills if they seem to lack them?**

I: Yes.

R: How should the skills be taught?

I: Hmm.[Long pause]. The problem, for me, is actually drawing the graphs, so they should, they should know when to use a line, ... when to use what type of graph, and how to distinguish between a dependent and an independent variable, so they can actually draw the graph properly, first time around without having to draw them five hundred times.

R: In your opinion who should teach the skills?

I: For the medics ..... they've got a graphing prac. So, you know, they should learn all the skills there. And if they have problems they should be able to go back and look what they've done in that prac and work out how,

..... where they are going wrong. So that's one of the pracs, one of the first pracs.

R: Do you think it's the university's responsibility or they should be taught at high school or something?

I: They're coming in off so many different levels that sometimes ..... they know exactly how to draw a graph, how to read a graph, and everything else, but sometimes they don't. So you need to standardize that everybody knows how to draw a graph when they get into the prac, that they need to draw a graph in.

R: So in your case, **what do you do, if anything, about teaching these skills?**

I: Well actually I see where they are having a problem and then you say to them "right why ....", you say .... you .... the axes .... and then you say to them "why, ... which is the independent variable, why? Which variable have you chosen?". " Okay. Well that is going to go wherever it's going to go". And then if they're having problems reading off, just to try to work out where they are going wrong, why they are not understanding how to read the information off the graph, which is, why they, ... the information is right there and why they can't get it off.

R: Do you use any particular strategy to teach the graphing skills?

I: No.

R: **Do you assess graphing skills?**

I: Ja we do have to mark graphs and that sort of stuff.

R: When do you assess them?

I: When we have to mark them. We have to take the pracs in to mark. And if there's something wrong in the graph then I always tell them why it's wrong and what they should have done to change it. But, we have to give a mark for the graph, so, ja.

R: So it's a continuous assessment?

I: [Sigh]. In the pracs that they have gotta draw graphs for. But if they don't have to draw a prac in the graph, ehh graph in the prac then, we can't assess them.

R: **Do you have any test or exam papers for me to look at the questions?**

I: [Pause and think]. Let me check.[Stands up and goes to get a practical manual from her book shelf].

R: Okay. Okay then thank you very much.

I: Okay sure.

R: That was all.