Evaluating the Impact of Electronic Voting Systems on University Mathematics Teaching and Learning

By

Samuel O. King

A Doctoral Thesis

Submitted in partial fulfilment of the requirements for the award of
Doctor of Philosophy of Loughborough University

September 2010

ABSTRACT

This thesis presents an evaluation of the impact of the use of Electronic Voting Systems (EVS) on mathematics teaching and learning, based on the research question: *What are the views of academic staff on the impact of EVS use on their mathematics teaching; and how has EVS use influenced student engagement and learning approach to mathematics?* To answer the question, a descriptive survey of academic staff, and semi-structured interviews with students were conducted; data from these studies were supplemented by classroom observations of EVS use, relevant documentary evidence, and preliminary studies conducted. Survey data was analysed via quantitative techniques; while the annotated interview transcripts were analysed via thematic analysis, and the application of an integrated theoretical framework. The validity, reliability and replicability of both studies were also established.

The findings show that feedback is viewed as the single, most beneficial impact of EVS use, as it enables instructors, through formative assessment, to identify student misconceptions, which then helps instructors to focus on the identified problem areas. EVS has also positively impacted student emotion, behaviour, and cognition. EVS use helps focus student attention, enhances participation and interactivity, and enables students to cognitively engage with learning material. The adoption of an integrated theoretical framework helps to characterise, and to reveal qualitative differences in student learning approaches. Also, the use of specific EVS question types tends to induce specific learning approaches in students.

Implications of the findings include the need for EVS-using instructors to have clearly defined pedagogical objectives and well-designed questions, and for learners to re-adapt their mathematical ideas in response to EVS feedback. Findings also show the need to incorporate instructional measures that would promote both procedural and conceptual learning approaches in students, and to perhaps rethink the role of calculator usage and guesswork in student approaches to learning. The requirements for technologies that may replace EVS, the need to align assessment with instructional practices, and for instructors to undergo further EVS training and/or form mathematics-specific support group(s) are also highlighted.

DEDICATION

This is dedicated to the all-seeing, all-knowing, all-wise and all-powerful God for giving me the strength to begin and complete this research project. To my guide, when the road seems dark and dreary; my anchor in the midst of storms and tempests; my inspiration on sunless, brooding days; and my strength for today, and the tomorrows yet in the womb of time.

ACKNOWLEDGMENTS

and typesetting.

To all the friends and acquaintances I have been fortunate to have here in Loughborough (including the Baca Project, Charnwood 20:20, King's and RCCG): Thank you very much. Your candour, support and enlivening conversations have helped add extra layers of incredible richness and colour to my life.

To Deremi and Biodun. To Florence and Danne, because I know I can always count on you. I am grateful for your unwavering support, prayers and dedication to my welfare.

LIST OF RELATED PUBLICATIONS

ACADEMIC JOURNAL ARTICLES

- King, S.O. & Robinson, C.L. (2009). 'Pretty Lights' and Maths! Increasing student engagement and enhancing learning through the use of electronic voting systems. Computers & Education, 53(1), 189-199.
- King, S.O. & Robinson, C.L. (2009). Staff perspectives on the use of technology for enabling formative assessment and automated student feedback. ITALICS, 8(2).
- King, S.O. (2008). Evaluating the cognitive aspects of visual tagging systems. International Journal of Interactive Mobile Technologies (IJIMT), 2(1), 18-23.

PROFESSIONAL JOURNAL ARTICLES

- Robinson, C.L. & King, S.O. (2009). Introducing electronic voting systems into the teaching of mathematics. MSOR Connections, 9(1), 29-33.
- King, S.O. (2009). Enhancing university mathematics teaching. Mathematics Today, 45.

REFEREED CONFERENCE PROCEEDINGS

- King, S.O. & Robinson, C.L. (2009). Formative teaching: A conversational framework for evaluating the impact of response technology on student experience, engagement, and achievement. The 39th Annual Frontiers in Education (FIE) Conference, San Antonio, Texas, October 18-21, 2009.
- King, S.O. & Robinson, C.L. (2009). Views of engineering students on the use of electronic voting systems in mathematics. In Green, D.R. (Ed.), Proceedings of the CETL-MSOR Conference, 57-62. Available online (Retrieved August 20th, 2010): http://mathstore.gla.ac.uk/repository/CETLMSOR2008_Proceedings.pdf.
- King, S.O. & Mbogho A.J.W. (2009). Evaluating the usability and suitability of mobile tagging media in educational settings in a developing country. Proceedings of the IADIS International Conference on Mobile Learning. Barcelona, Spain, February 26-28, 2009.

- King, S.O., Robinson, C.L., Davis, L., Croft, A.C., & Ward, J.P. (2008). Staff reflections on the one tablet mathematics classroom. The 11th International Congress on Mathematical Education (ICME11), Topical Study Group 5 (TSG 5). Monterrey, Mexico, July 6-13, 2008.

EDITED CONFERENCE PROCEEDINGS

- King, S.O., Davis, L., Robinson, C.L., & Ward, J.P. (2008). Use of voting systems in lectures at Loughborough University: A review of staff experiences. Mathematical Education of Engineers (MEE 2008) - 14th Joint Conference of Mathematics Working Group of the European Society for Engineering Education (SEFI) and the Institute of Mathematics (IMA). Mathematics Education Centre, Loughborough University, Loughborough, England.

GLOSSARY

ALT	Approaches to Learning Theory
APOS Theory	Actions, Processes, Objects, Schemas Theory
BBC	British Broadcasting Channel
BODMAS	Brackets, Orders, Division, Multiplication, Addition and Subtraction
BOS	Bristol Online Survey
CAA	Computer-Aided Assessment
CAMC	Case and Marshall Criteria
CAS	Computer Algebra Systems
CAQDAS	Computer-Aided Qualitative Data Analysis Software
CA	Conceptual Approach
CD	Contextual Deep
CE	Conceptual-Embodied
CETL	Centre for Excellence in Teaching and Learning
CIA	Computer-Intensive Algebra
CU	Conceptual Understanding
DGEs	Dynamic Geometry Environments
DGS	Dynamic Geometry Systems
DP	Deliberate Practise
ESTICT	Engaging Students Through In-Class Technology
et al.	et alli (and others)
EVS	Electronic Voting Systems
FIE	Frontiers in Education Conference
HUs	Hermeneutical Units
GCSE	General Certificate of Secondary Education
HELM	Helping Engineers Learn Mathematics
IADIS	International Association for Development of the Information Society
IAMP	Improving Attainment in Mathematics Project
ICME	International Congress on Mathematical Education
IDN	I Don't Know
IJIMT	International Journal of Interactive Mobile Technologies
ILOs	Intended Learning Outcomes
IM	Instant Messenger
IMA	Institute of Mathematics
MCQs	Multiple-Choice Questions
MEC	Mathematics Education Centre
MEE	Mathematical Education of Engineers
MSOR	Maths, Stats and Operational Research
NMAP	National Math Advisory Panel

NRC	National Research Council
PA	Procedural Approach
PCs	Personal Computers
PD	Procedural Deep
PDs	Primary Documents
PhD	Doctor of Philosophy
PS	Procedural Surface
PU	Procedural Understanding
QA	Question and Answer (session)
QDI	Question Driven Instruction
SEFI	European Society for Engineering Education
TSG 5	Topical Study Group 5
TTW	Tall's Three Worlds (of Mathematics)
TwEVS	Twitter Electronic Voting Systems
UK	United Kingdom
US	United States
USB	Universal Serial Bus
USDoE	US Department of Education
VLEs	Virtual Learning Environments

TABLE OF CONTENTS (OVERVIEW)

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE

INTRODUCTION

Test scores were not significantly higher in classrooms using selected Reading and Mathematics software [i.e. educational technology] products. Test scores in treatment classrooms that were randomly assigned to use products did not differ from test scores in control classrooms by statistically significant margins.   *(Dynarski et al, 2007, pxiii)*

1.1 INTRODUCTION

In 2007, the Department of Education in the US released the findings of a study into the impact of selected software products on student achievement in mathematics and reading. One of the main findings was that student use of the educational technology products did not appear to lead to any significant learning gains (Dynarski et al, 2007). Although there have been many objections to the conclusions of the study (e.g. Nagel, 2007), the report did raise a fundamental issue: *The need to evaluate the impact of educational technology products and innovations on student learning*.

Too frequently, educational technologies are promoted and adopted for use in schools and universities without compelling (research or practitioner) evidence about their impact on teaching and learning. The promotion and use of technology in education is often analogous to the scenario of a dancing bear. Yes, the bear is dancing, but is it dancing *well*? For example, Highfield & Goodwin (2008, p1) claimed that 'the proliferation of technological tools in Australian mathematical classrooms has not been well-supported by evidence-based research...'. Similarly, Hoyles & Noss (2003) claimed that the impact of 'puzzle-style software', which in the UK is possibly the most ubiquitous application of technology in mathematics classrooms…remains largely unresearched' (p3).

The realisation that the proliferation in the use of specific educational technologies is not necessarily linked to evidence of the beneficial impact of such technologies leads to the question: What is the research evidence about the impact of technology on mathematics teaching and learning? In the next section, I will present a concise literature review about the impact of technology on mathematics teaching and learning. Then in subsequent sections, I will introduce the educational technology

whose impact on mathematics teaching and learning is being investigated in this thesis, and then describe the research goal, questions and design adopted for the studies presented in this thesis. This will be followed by a synopsis of the (preliminary) studies which informed and/or contributed to the studies presented in this thesis, but which have not been included due to volume constraints. Then in the last section of this chapter, I will present the thesis outline i.e. a synopsis of the contents of the individual thesis chapters.

1.2 TECHNOLOGY IN MATHEMATICS EDUCATION LITERATURE REVIEW

There are many documented barriers to learning mathematics at the tertiary level. These include *maths anxiety* or fear of doing mathematics, the seeming apathy or passivity that students exhibit in lectures, the perceived mathematical unpreparedness of students for university mathematics, and the prevalence of pedantic teaching in mathematics lectures (e.g. Hawkes & Savage, 2000; NMAP, 2008; NRC, 2001; Croft et al., 2000; Sawyer, 1943; McLeod, 1992). A number of initiatives and projects have been initiated in a bid to overcome these barriers (e.g. Croft & Ward, 2001; Dalhberg & Housman, 1997; NMAP, 2008; Novak et al, 1999). Further, the use of technology is increasingly seen as part of the initiatives to overcome barriers to effective mathematical instruction. The vastly increased visibility and use of educational technologies in mathematical instruction is partly based on the recognition of the fact that the appropriate use of educational technologies can help overcome some of the barriers to learning mathematics (e.g. Skemp, 1978; Hoyles & Noss, 2003; Burton & Jaworski, 1995). In this section, I will present literary evidence about the role of technology in mathematics education. As my aim is to present an overview of the research evidence, I will be focusing only on a few studies which are themselves literature reviews and/or synthesis of the influence of technology on mathematics education.

These studies were chosen not only because they are comprehensive reviews of the role of technology in mathematics education, but also because they are either based on rigorous research undertaken via national/international initiatives or agencies (e.g. NMAP 2008; Hoyles & Lagrange, 2009; Underwood, 2009; Schacter, 1999), or are written by established scholars in the field of technology in mathematics education (e.g. Laborde & Strasser, 2010; Olive et al, 2009; Hoyles & Noss, 2003). The review

presented, which is a review of the reported evidence of the impact of technology on mathematics education, is thus predicated on 17 studies (out of the initial 47 which I identified), which met the criterion earlier highlighted. The evidence from the review of these 17 studies indicates that the (positive) impact of technology could be classified into nine dimensions. These nine dimensions will be presented in the next section.

1.2.1 IMPACT ON THE NATURE OF MATHEMATICS

The use of technologies in mathematics education appears to have changed the nature of mathematics itself i.e. the adoption of technology often 'reshapes the cultures of mathematical learning' (Hoyles & Noss, 2003, p14). Olive et al. (2009) posited that technology usage has influenced 'both the nature and construction of mathematical knowledge…in ways that create a new learning ecology' (p150). Examples of this emergence of a new learning ecology, i.e. new mathematical knowledge and practices, are evidenced by the following:

The emergence of new fields

The emergence and subsequent enhancement of new sub-disciplines or fields of enquiry such as computational mathematics, mathematical and statistical modelling, dynamic geometry, robotics and digital games, etc are partly attributable to the use of educational technologies (Lavicza, 2010, p106; Laborde & Strasser, p124; Olive et al, 2009, p133, 168; Bransford et al, 2000). Olive et al. (2009) posited that the emergence of the new learning ecology is a result of the *accommodation* of technology i.e. the adaptation of the mathematical learning environment for the incorporation of technology usage, such that technology *can* shape the knowledge and practices of the mathematics so produced (p135).

Knowledge required for doing mathematics

The use of the *drag* mode in Dynamic Geometry Systems (DGS) enables students to make 'sense of functional relationships and graphs without the necessity of an algebraic representation' (Hoyles & Noss, 2003, p2; see also Arcavi & Hadas, 2000). Further, Goldenberg (1995) posits that the 'line segments' constructed in DGS environments are 'not the same objects that one treats in the familiar synthetic geometry' (p220, as quoted in (Hoyles & Noss, 2003, p12). In addition, Olive et al. (2009) described how calculator usage enables students to perform 'microprocedures', so the student could

focus on 'macroprocedures, which require higher level processing' (p159).

New mathematical practices

New mathematical practices have become entrenched, especially with the use of DGS and Computer Algebra Systems (CAS) tools. A principal and ubiquitous practice deriving from the use of CAS is the notion of dragging. Olive et al. (2009) posited that the 'most obvious new practice made possible by DGSs is the ability to drag elements within a construction and thus rapidly visualise many possible examples of the construction' (p160).

The mathematics being taught

'Learning about software [e.g. Maple, Cabri, GeoGebra, Latex, etc] increasingly becomes an integral part of learning mathematics' (Hoyles & Noss, 2003, p2). Many first year students in mathematics departments across the UK are required to take an introductory (or section of a) course on the relevant mathematical software.

1.2.2 ROLE OF INSTRUCTOR

The evidence suggests that the use of digital technologies leads to an alteration in the relationship between students and their instructor(s), such that the instructor becomes 'more of a leading team player than a sole dispenser of knowledge' (Becta, 2003; see also Lavicza, 2010, p107; Hoyles & Noss, 2003, p16). Laborde and Strasser (2010) expanded on the role an instructor has to assume when technology is used as being characterised by the teacher becoming more of a 'stimulant, a manager of learning, an orchestrator of the interactions between technology and students' (p125). This 'redefinition of epistemological authority' (Bransford et al., 2000, p270) within the technology-facilitated classroom leads to a 'shift in empowerment (Olive et al, 2009, p133) away from the instructor and towards the students. This shift is often characterised by 'less lecturing' and more student involvement (Olive et al, 2009, p155; see also Schacter, 1999, p5). Olive et al (2009) described the shift to students thus: 'Control shifts more to the student in making decisions about how to utilise the technology in problems that do not "tell" which mathematics is needed upfront' (p155). However, this shift is not always positive, especially in instances where epistemological authority is merely transferred from instructor to the technological tool being used i.e. when students see 'technology as master' instead of viewing 'technology as partner [or]

servant' (Olive et al, 2009, p156).

1.2.3 INSTRUCTOR COMMUNITY

The use and proliferation of digital technologies, especially social media, have not only redefined the role of an instructor and the means by which they interact with their students, they have also afforded instructors the means to build practitioner or learning communities. These affordances include the availability and use of blogs, wikis, listservs or mailing lists and databases/instructional material archives (Bransford et al, 2000, p228) for sharing mathematical knowledge. These tools enable the development of 'local and global communities of teachers', which thereby expand 'opportunities for teacher learning' (Bransford et al, 2000, p243). These are the same tools that have led to a more rapid delivery and uptake of virtual learning (Underwood, 2009).

1.2.4 LEARNING GAINS (STUDENT ACHIEVEMENT)

Many of the studies reviewed report learning gains or increases in student achievement on requisite assessment measures as a direct result of the use of educational technologies. Becta (2003) reports that technology usage has been shown to produce 'learning gains in graph interpretation' (p2). Evidence from the large scale Impact2 study (Harrison et al, 2002; see also Becta, 2009) showed that there was a positive relationship between the use of technology and significant improvement in student attainment at school level. Further, Schacter (1999) reported that 'students who used computer instruction' scored higher on 'tests of achievement' than students who did not use computers under control conditions, based on the Kulik (1994) study (p4). Schacter also reported that, based on the Sivin-Kachala (1998) study, 'students in technology rich environments showed increased achievement in preschool through higher education for both regular and special needs children' (p5). Similarly, Schacter provided evidence from the Wenglinsky (1998) study that showed that 'simulation and higher order thinking technologies' positively impacted students' academic achievement (p7). Other research evidence for the beneficial impact of educational technologies on student achievement includes USDoE (2009), Underwood et al. (2009), Schacter & Fagnano (1999), Besa (2006) and Kennewell (2006).

1.2.5 CONCEPTUAL UNDERSTANDING

Heid (2003) reported that students in Computer-Intensive Algebra (CIA) classes showed a 'much deeper conceptual understanding of fundamental algebraic ideas (such as function, variable, and mathematical modelling)' than their traditional course peers (p3). She also reported that students taught calculus in classes utilising CAS did 'significantly better on conceptual tasks with little or no loss to by-hand symbolic manipulation skills' (p2). Moreover, DGS and CAS tools aid student development of conceptual understanding by helping to focus students' attention on the difference between drawings that can be messed up by dragging…and figures whose geometrical properties are retained under dragging [i.e. they are invariant]'(Hoyles & Noss, 2003, p11) . The use of graphing technology helped students develop 'higher levels of graphical understanding…, deeper understanding of functions…, [and] better understanding of connections among a variety of representations' (Heid, 2003, p4).

1.2.6 FEEDBACK

A common reported benefit of the use of interactive technologies is the provision of feedback to students. Through the use of these technologies, students 'receive feedback [which they could then use]…to continually refine their understanding and build new knowledge' (Bransford et al, 2000, p206). The technologies that explicitly or implicitly provide students with feedback include Computer-Aided Assessment (CAA) software, tutoring systems, student response systems such as EVS or classtalk, graphing calculators, CAS and DGS tools. Feedback from the interactions of students with these tools have a 'strong impact on their mathematical understandings and practices' (Olive et al., 2009, p159; see also Bransford et al, 2000, p219). An example of how this may be achieved is how feedback may facilitate a shift in student attention from 'micro-procedures (that the tool performs) towards macro-procedures that involve higher-level cognitive processes' (Olive et al, 2009, p167; see also Becta, 2003, p2). Moreover, DGS and also CAS tools provide 'a kind of feedback that is not readily evident in paper-and-pencil construction, [one] that distinguishes between a result, a *drawing*, created without concern for the underlying geometrical relationships, and one, a *figure*, that has been constructed through the use of geometrical primitives and relationships' (Hoyles & Noss, 2003, p11).

1.2.7 PROBLEM SOLVING

There is incontrovertible evidence that technology enables students to improve their speed, accuracy and aptitude in solving mathematical problems. Laborde and Strasser (2010) stated that 'with technology, mathematics becomes more experimental and allows students to change the conditions of the problem, check strategies and receive feedback' (p124). Instructional technologies such as drill and practice software, tutoring systems and teaching computer programming such as Lego have been shown to have beneficial impact on student problem solving skills (NMAP, 2008, xxiii; see also Bransford et al., 2000, p209, 213, 223; see also Schacter, 1999). Heid (2003) also reported that the use of graphing technology helped students to do better work in 'interpreting and relating graphs to their symbolic representations' as well as enhanced their 'ability to think about function graphs without software (p4).

1.2.8 AFFECT

Perhaps the most recurring benefit of the incorporation of educational technologies into learning environments is the impact they have on affect or emotional well-being. The authors of the Becta (2003) study stated that 'maths curriculum software has been shown to motivate both teachers and pupils' … [and] 'to overcome pupils' apprehensions' (p2). The Becta review also posited that technology usage led to 'increased motivation (p1) and a feeling of 'pleasure' (p3). Similarly, Schacter (1999) reported that students in classes with computer-based instruction 'like their classes more and develop positive attitudes' (p4; see also Bransford et al., 2000, p209), and their 'self-concept improved consistently' (p5). In addition, Olive et al. (2009) provided evidence of the use of graphing calculators to stimulate student interest (p155), and the use of technology to motivate students (p154).

1.2.9 BLURRING OF SCHOOL AND OUT-OF-SCHOOL CONTEXTS

Student adroitness at using digital technologies and the provision of Virtual Learning Environments (VLEs) have blurred the previously distinct boundaries between school and out-of-school (e.g. home) environments. Students use these technologies to 'make connections' (Bransford et al, 2000, p224) between the two contexts: 'Today's students use technology (Instant Messaging, Facebook, Flickr, Skype) to be constantly connected' (Oblinger, 2008). Although most of these connections are not learning-

focused, students often use these tools to collaborate with their peers to learn relevant lecture material (Oblinger, 2008). One benefit of these connections is the finding that 'having access to a computer at home is associated with a 5.8% reduction in the likelihood of playing truant at age 16' (Underwood, 2009, p3).

1.2.10 SUMMARY

In this section I have presented a synthesis of the research literature dedicated specifically to a review of the impact of educational technologies on mathematics teaching and learning. This synthesis highlighted nine dimensions of mathematics education which have been impacted by the use of educational technologies. These dimensions include an explanation of how technology has changed the nature of mathematics and redefined the role of instructors, while affording them i.e. the instructors the means to build local and global teaching and learning communities. I have also highlighted how the use of technologies has led in specific situations to improvement in student achievement, helped students develop better understanding of the requisite concepts, improved their problem solving ability and provided them with rich and varied forms of feedback which are usually not available in traditional classroom environments. In addition, I have presented evidence on how technology usage has contributed to an improvement in student (and often, instructor) emotional identification with teaching and learning goals.

In the next section, I will introduce Electronic Voting Systems (EVS), an educational technology tool that will be the main focus of this research project. But I should point out at this juncture that my focus on EVS is a contribution to the literature on the impact of educational technologies, as my research will be focusing on the evaluation of the impact of EVS use in mathematics teaching and learning, as an educational intervention. Second, my focus on EVS use at university level is significant because of the reported paucity of research on the use of educational technologies in universities and colleges (see Lavicza, 2010, Laborde & Strasser, 2010).

1.3 INTRODUCING ELECTRONIC VOTING SYSTEMS

1.3.1 BACKGROUND

As stated in the preamble to the literature review of technology in mathematics education, there is awareness in the mathematics community that technology could help enhance mathematics teaching and learning. This awareness is one reason why academic staff at the Mathematics Education Centre (MEC) began using the EVS and tablet computers for the teaching of mathematics at Loughborough University in the 2007/2008 academic year. At about the same time, I was offered a three-year research studentship to investigate the associated impact of EVS use on mathematics teaching and learning. Therefore, this thesis will focus exclusively on the studies I conducted to evaluate the impact of EVS use. But first, I would like to introduce EVS and how it has been used in mathematics lectures at Loughborough University.

Figure 1.1 Students using EVS (TurningPoint) handsets to register their responses to a question in class[1].

1.3.2 DESCRIPTION OF EVS

EVS is an educational tool that can be used in a class, at its most basic, in the same manner polling devices are used on the television programme, 'Who Wants to Be a Millionaire' (Ask the Audience section). The EVS technology being used at

---

[1] Used with permission of Turning Technologies.

Loughborough University is supplied by Turning Point[2], and consists of *handsets* which are similar in shape, design and function to small television remote control units; a *receiver* or *dongle* which is essentially a USB device that is plugged into a computer port; and the *enabling software* which has to be downloaded to a computer. A lecturer uses the software on the computer to create (usually multiple choice) questions which can be presented to students in class. The students answer the questions by clicking the corresponding alphanumeric answer choice on their EVS handsets (Figure 1.1). Student responses are then displayed, also in real time, in the form of a suitable chart (Figure 1.2). The lecturer may then decide to elaborate on any relevant issues arising out of the question and answer display session. For instance, a lecturer should address why options (1), (2) and (4) in Figure 1.2, which 54% of the students in a class had selected as the correct option, are in fact incorrect.
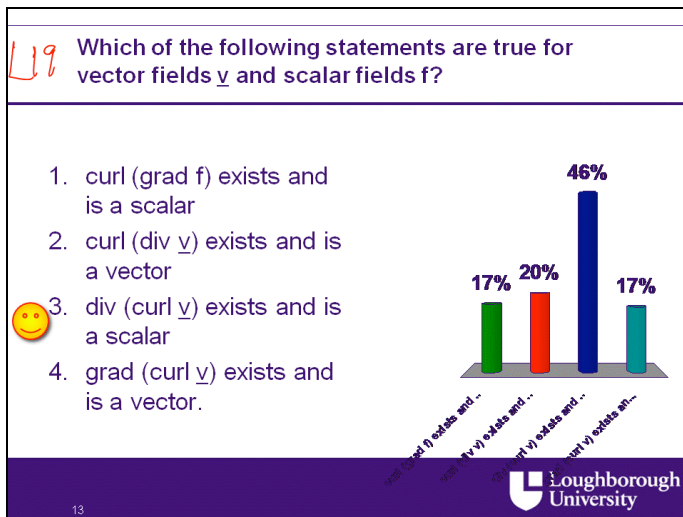
Figure 1.2 Chart showing student response to an EVS question.

EVS is therefore a technology that affords an instructor the means to give students, especially in a large class, the opportunity to engage with course material by having them answer questions during a lecture, with subsequent provision of feedback to students. In the next section, I will present a more detailed background of EVS use in education, with respect to its history, ownership and usage models, and types and

---

[2]

http://www.turningtechnologies.co.uk/index.php?option=com_content&view=article&id=9&Itemid=4

usage modes. The section will also feature a concise literature review, pedagogical objectives for using EVS, and the predominant pedagogical purpose for the use of EVS at Loughborough University for mathematics teaching.

History

The first reported use of a device similar to EVS in higher education was by H. Richard Crane at the University of Michigan in 1961 (Hake, 2008). Another early pioneer, Ralph Littaeur, who was also a physicist, used similar systems at both Stanford and Cornell universities in 1966 and 1968 respectively (Hake, 2008; Abrahamson, 2006, p3). So EVS-like systems have been in use in higher education for over 40 years. In the UK, the early pioneers are Jim Boyle of Strathclyde University, who started using an EVS-like system at about the year 1998, and also Michael McCabe of Portsmouth University, at about the same time. Today, EVS systems are used not only in higher education, but also at pre-university levels. For example, Abrahamson claimed that 'a cursory web search, conducted in early 2005 found names of over 3,000 school buildings at the primary and secondary levels in the USA also using response systems' (p2).

EVS ownership and usage models

Based on current practice in the US and UK, there are three modes of EVS acquisition and use in university classrooms. These are the student purchase, student ownership for a specified period, and student ownership/use on a lecture by lecture models. In the US (e.g. Purdue University and University of Wisconsin-Milwaukee), the model is for students to purchase their own EVS handset at the beginning of a semester, so each student has a personal EVS. In the UK, students are usually not required to purchase their own EVS, but there may still be student ownership, depending on institutional practice.

At Surrey University for example, students are required to borrow EVS from the library and keep for use for the duration of module(s), usually a semester, where EVS use is required. Hertfordshire University also operates a student ownership model. At Glasgow and Loughborough Universities, however, student ownership of EVS is on a

lecture-by-lecture basis. This means that students collect EVS at the beginning of a lecture where EVS will be used, and then return the EVS at the conclusion of the lecture. But the common element to EVS acquisition in the UK is that the appropriate university department, such as Teaching Support at Loughborough University, usually purchases the EVS. Departments and staff within the institution are then invited to apply for the use of the EVS.

Types and Usage of EVS Systems

From a user perspective, there are two broad groups of EVS systems: Those that allow only alphanumeric input, and those that are more flexible, such that they allow free text input. The latter are designed more like mobile phones, while the former are like TV remote control devices. All the major vendors, including Turning Point, e-Instruction (incorporating InterWrite and Classroom Performance System, CPS)[3], i>clicker[4], Qwizdom[5], Promethean[6], and H-ITT[7] usually provide both sets of EVS systems (see item 5 in the questionnaire presented in Appendix A for a list of the EVS systems which are commonly used in the UK). In addition, it is often possible with some systems for students to indicate the level of confidence with which they are answering a particular question. So a student may, for example, indicate that an answer choice for a particular question was selected with low, medium or high confidence (Bruff, 2009, pp 98-112; Draper, 2010, p3).

Moreover, it is also possible to link individual students with specific handsets, under the student purchase or student ownership models. It would then be possible to either record student attendance, or monitor individual students' academic progress on a particular module during the academic calendar (e.g. Russell, 2008). Struggling students may thus be identified, and provided with additional help, if required. It should be noted that the handsets used by students interviewed for this thesis are not linked to individual students. It is also not possible for students to identify the confidence levels

---

[3] http://www.einstruction.com/index.html

[4] http://www.iclicker.com/dnn/

[5] http://education.qwizdom.co.uk/

[6] http://www.prometheanworld.com/server.php?show=nav.16

[7] http://www.h-itt.com/

with which they answer questions because the handsets do not have this utility – see Wilson (2006) for a comparison of the functionalities of the different EVS systems available.

Concise review of EVS use in higher education

A wide array of literature that includes three books, Duncan (2005), Banks (2006) and Bruff (2009), exists on the use of EVS in the US, UK and other countries. So this section will focus on a concise review of two broad groups of publications that have been written on the use of EVS in university education. First, there will be a synthesis of the publications that have quintessentially been topical expositions of papers that have been published on the use of EVS in higher education. Second, there will be a review of a cross-section of papers that have focused on reporting evaluations of student perceptions of EVS use in higher education.

Caldwell (2007), a review of existing literature on EVS use, is a comprehensive and detailed work that covers every aspect of EVS use including description of the technology, use of questions, effect on student performance and association of EVS with 'peer learning'. The study also includes guidelines for writing good questions and best-practice tips. Caldwell however claims that ''. . .much research remains to be done to elucidate the reasons why EVS are effective" and also that ''. . .the research so far is not systematic enough to permit scientific conclusions about what causes the benefits".

Simpson and Oliver (2007) categorises the literature on EVS, based on the maturity and increasing depth of research publications, into two timelines: (I.) Pre-2002 and (II.) Post-2002 (2002–2006). Distinctive contributions of this paper include the propositions that ''Voting systems are best understood as a tool rather than a teaching approach", a view also supported by Fies and Marshall (2006). The authors however cautioned that practice and research into EVS use has tended to remain ''. . .in the preserve of the enthusiast", without much emphasis on how the use of EVS ''. . .impact on learning and net benefit".

The goal of the Fies and Marshall (2006) publication was to highlight the areas of EVS research that require increased focus or greater depth. These areas include the adoption of more rigorous methodologies, study of effect of EVS use by diverse student populations and increased emphasis on the evaluation of benefits of EVS use in ''group

discussion" mode.

In Roschelle, Penuel and Abrahamson (2004), the authors present a theoretical approach code-named CATAALYST, which is based on a formative assessment framework. The authors claim that the CATAALYST approach ''improves achievement" and they also use motivational goal theories to explain how the approach ''creates greater engagement and broader participation".

In Simpson and Oliver (2002), the authors identify, based on literature review, three key measures (of what ''counts as good learning") to use in evaluating the effectiveness of EVS use. These measures are: The inadequacy of the lecture format as a medium for mere 'content transmission'; active engagement; and quality feedback. Further, the paper lists six benefits that may accrue with the use of EVS while also identifying 12 ways in which EVS have been used.

Publications focusing on student perceptions of EVS use include Zhu (2007), which was based on a study of the use of EVS at the University of Michigan. In contrast to the Simpson and Oliver (2002) study, Zhu, based on student perceptions of EVS, identified seven ways in which faculty use EVS, and also proffered a list of 14 recommendations on how to use EVS. The MacGeorge et al. (2008) study, on the other hand, adopted a ''multi-survey" design that tracked student responses over the course of a semester while the effect of student diversity on perceptions of EVS use was also measured. The authors also stressed that the impact of instructor approach to the use of EVS requires further research.

Similarly, Kaleta and Joosten (2007) sought to measure student attitudes as well as the impact of EVS use on grades and retention at the University of Wisconsin. The reported findings are consistent with those reported elsewhere in that student attitudes were generally positive – with slight improvements and reductions in grades and retention respectively. In Cline, Zullo and Parker (2007), the authors describe the use of coloured cards to stimulate engagement and 'peer discussion' in their classes and then contrasts this approach with the functionality afforded by the use of EVS, which were later introduced into the authors' classes.

Pedagogical objectives for using EVS

There are several ways of classifying the pedagogical objectives that EVS may be used to achieve in the classroom. Bruff (2009) lists five pedagogical goals for using EVS. These include: Generating classwide discussions (p6), Generating small group discussions (p14), Creating times for telling i.e. highlighting common student misconceptions (p27); Structuring class time to facilitate student attention (p32), and Making class more fun (p35). Further, these five goals may be broadly classified into formative and summative assessment goals.

Based on these pedagogical objectives, Bruff explained that EVS questions may be generally classified into two broad groups: Content and Process questions. Content questions 'directly assess student learning…and focus on course content and often have correct and incorrect answers' (p72). Examples of these include Recall, Conceptual Understanding, Application, Critical Thinking and Free-Response questions (Bruff, 2009, pp 72-98). Process questions 'are used to gather information from students helpful in shaping how they interact with each other during class and with course material' (Bruff, 2009, p98). Examples of these are Student Perspective questions, Confidence Level questions (i.e. questions to which students respond by indicating their levels of confidence with respect to the answer choices selected), Monitoring questions, and Classroom Experiments (Bruff, 2009, pp 98-112)

Draper (2010) identifies five pedagogical objectives for using EVS. These include: Contingent teaching – this is often referred to as agile teaching in the US (Beatty et al., p105; Bruff, 2009, p47), Peer discussion, Convening of remediation sessions before or after mandatory assessments, Peer assessment, and Collection of experimental data. Draper also highlights five questions that may be used to promote meaningful student engagement with learning. These include: Assertion-reason questions, which are questions 'involving the linking of facts to theories or reasons' (p3); Confidence-based marking (p3); Conceptual questions induced by the use of brain teasers (p4); Student-generated questions (p5); and Multi-response questions, where learners 'generate reasons, for and against each response option, rather than simply ticking one' (p6).

Formative teaching

The predominant pedagogical purpose for the use of EVS (questions) at Loughborough University, specifically on the mathematics module that will be presented later in this thesis, is the use of the technology to enable formative teaching. Formative teaching refers to the intentional design and creation of a learning environment where active student questioning and feedback are an integral part of the lecture experience for students in a class.

The formative teaching approach is a variant of the Question Driven Instruction (QDI) paradigm (Beatty et al., 2006), a variant because peer discussion is not a major goal – although students on the engineering mathematics module being investigated have often been asked to discuss their answers with their peers. A typical lecture might feature up to eight EVS multiple-choice questions, depending on the topic and the learning outcomes envisioned for that particular lecture. Later in this thesis (Chapter 6.3), I will present more details about formative teaching, and the types of EVS questions that have been used within this paradigm, as well as how these question types influence the approaches that students adopt towards learning mathematics.

In the next section, the research goal, questions and design of the studies conducted to evaluate the impact of EVS on mathematics instruction will be presented.

1.4 RESEARCH GOAL, QUESTIONS AND DESIGN

1.4.1 RESEARCH GOAL

The main goal of the research presented in this thesis is: The evaluation of the impact of EVS use in enhancing the teaching and learning of university mathematics.

1.4.2 RESEARCH QUESTIONS

To realise the research goal above, the following research questions were devised:

1. What are the views of academic staff using EVS on the impact of the technology on their teaching of university mathematics (the focus of Chapter Two in this thesis)?

2. How has the use of EVS impacted (or otherwise) student engagement with

respect to the learning of mathematics at university (Chapter Four)?

3. What is the student's approach to learning mathematics (Chapter Five)? and How has the use of EVS questions influenced (or otherwise) student approach to learning mathematics (Chapter Six)?

The first research question deals largely with *teaching* issues, while the remaining research questions are largely related to investigating the impact of EVS on *learning*. The studies which were conducted to evaluate the impact of EVS, and which will be presented in Chapters Two, Four, Five and Six, were essentially undertaken to provide insights into the research questions above. In the next section, I will present the research design I adopted.

1.4.3 RESEARCH DESIGN

The research design for the studies presented in this thesis is patterned after the *inductive* approach (Bryman, 2008) i.e. 'the process of induction involves drawing generalisable inferences out of observations [or results obtained from studies conducted]' (p11). The studies conducted have therefore been shaped by the scope and tenor of the research questions which have subsequently informed the data collection methods used, as well as the interpretation of the findings.

Further, the studies presented in this thesis are predicated on an *interpretive* epistemological framework – epistemology 'concerns the question of what is (or should be regarded) as acceptable knowledge in a discipline' (Bryman, 2008, p13). The epistemological approach is interpretive because the findings are presented as representations or characterisations of the impact of EVS use on mathematics teaching and learning, based on *my interpretations* of the relevant data. Similarly, the ontological position of this thesis is broadly *constructionist* in the sense that the research accounts presented are 'a specific version of social reality [of the impact of EVS use], rather than one that can be regarded as definitive [or only possible account]' (Bryman, 2008, p19).

Methodology: Quantitative Research Paradigm [Chapter Two)

To answer the first research question on staff views of EVS, a study predicated on a *quantitative* research methodology, i.e. the 'collection of data on more than one case…at a single point in time in order to collect a body of quantitative or quantifiable data…, which are then examined to detect patterns of association' (Bryman, 2008, p44), was conducted. Further, survey research, a type of cross-sectional research design

(Bryman, 2008, p46), was adopted as the main data collection method. The decision to use a survey was made because it provided the best *fit-for-purpose* (Cohen, Manion & Morrison, 2007, p501) with respect to answering the research question. This is why the survey type employed is *descriptive survey* research because this type of inquiry enables a researcher to 'look at individuals, groups, institutions, methods and materials in order to describe, compare, contrast, classify, analyse and interpret the entities and the events that constitute their various fields of inquiry' (Cohen, Manion & Morrison, 2007, p205). The adoption of descriptive survey research therefore enables me to collect data and to *describe, compare, contrast, classify, analyse and interpret the findings* with respect to how staff in the UK use EVS to enhance the teaching and learning of university mathematics.

Detailed information about the quantitative research paradigm is presented in Chapter 2.2.

Methodology: Qualitative Research Paradigm [Chapters Four, Five and Six]

To answer the remaining research questions, a study predicated on a *qualitative* research methodology, i.e. 'a research strategy that usually emphasizes words rather than quantification in the collection and analysis of data…' (Bryman, 2008, p22), was conducted. Further, a semi-structured interview (Bryman, 2008, p438; Cohen, Manion & Morrison, 2007, p352) approach was employed to interview 10 volunteer students. As a result of the preliminary studies conducted (see Section 1.5), I had acquired substantial knowledge on the ways that EVS use may influence learning. However, there were still many gaps in that knowledge. Therefore, the semi-structured interview approach (Bryman, 2008, p438; Cohen, Manion & Morrison, 2007, p352) was adopted as the most effective means of addressing these 'gaps', in agreement with the recommendation that: 'The structured interview is useful when researchers are aware of what they do not know and therefore are in a position to frame questions that will supply the knowledge required' (Cohen, Manion & Morrison, 2007, p354).

Detailed information about the qualitative research paradigm is presented in Chapter 3.

Mixed-methods approach

Moreover, the research accounts presented are predicated on a mixed-methods approach (e.g. Greene & Caracelli, 1997), with integration of qualitative and quantitative research methods such as observations, interviews, and surveys. The rationale for the adoption

of this approach is that it would lead to robust data collection, synthesis and interpretation (MacGeorge et al., 2007), such that the research findings benefit from, or have maximum exposure to the inherent strengths of the composite methods used, while having limited exposure to their deficiencies.

Theoretically, the two constructs of the mixed-methods approach that I have adopted include *Completeness*, the 'notion that the researcher can bring together a more comprehensive account of the area of enquiry in which he or she is interested if both quantitative and qualitative research are employed' (Bryman, 2008, p609); and *Enhancement*, i.e. 'building upon quantitative/qualitative findings…[which] entails a reference to making more of, or augmenting either quantitative or qualitative findings by gathering data using a qualitative or quantitative research approach.

An example of the application of the dual completeness/enhancement principle is in Chapter Four, where both quantitative/qualitative methods have been utilised. In that chapter, a qualitative method, semi-structured interviews, and a qualitative analytical technique, thematic analysis, are used to present and analyse the findings about the impact of EVS use on student engagement. Then a quantitative method, a frequency table, is used to highlight the association between regular EVS use and increase (or otherwise) in student achievement). This dual principle is also exemplified in Chapter Two where both quantitative/qualitative methods are used. In that chapter, quantitative methods such as, frequency and correlation tables, are used to analyse the findings of survey data. But a qualitative analytical technique, thematic analysis, is also employed to analyse open-ended submissions from respondents.

1.5 BACKGROUND STUDIES

Due to volume constraints and the need for coherence, some of the (preliminary) research studies I conducted as part of the investigation into the effectiveness of EVS for mathematics teaching and learning are not included in this thesis. However, these studies informed or contributed to the studies that are presented. For instance, the design and conduct of the study presented in Chapter Two was informed by the Staff Survey (2008) study presented below. Moreover, three of these studies have already been published as peer-reviewed journal or conference papers. In this section, I will present in chronological order an overview of the preliminary studies that are not included in this thesis.

Student Survey (2008) Study: Evaluating the Impact of EVS Use on Student Attitudes, Participation Rates and Academic Performance

The study was designed to determine student attitudes about EVS usefulness for learning; evaluate the impact of handset use on student participation rates or engagement in class; and highlight the impact (or otherwise) of handset use on student academic performance. The sample consisted of 145 second-year students drawn from the Automotive, Aeronautical and Mechanical Engineering Departments at Loughborough University. The methodology consisted of a mixed-methods protocol and comprised the use of observations, informal feedback and surveys.

The findings show that students generally have positive views about EVS usefulness, with 80% of students stating that they found handsets 'useful' or 'very useful'. Although handset use has some drawbacks and not all students have participated by using the handsets in class, yet the consensus, from student responses, is that EVS is seen as being overall advantageous to their learning. The benefits of EVS use that have been identified in research literature, such as feedback and problem identification, were also independently confirmed by the students sampled. Student association of EVS use with fun, and how this may be beneficial to learning, was also highlighted. The findings also show that handset use does increase the likelihood of students participating and engaging in class, compared to other common student response solicitation methods, like raising of hands and volunteering a verbal response. Further, even students who do not view handsets as being particularly useful stated that they are more likely to participate in classes where handsets are used than otherwise.

This study has been written up as a journal article (i.e. King & Robinson, 2009b).

Staff Survey (2008) Study: Staff Views on EVS Usefulness for Teaching

The aim of the study was to answer the research question, *What are staff experiences and perspectives on the use of EVS in lectures, and the associated pedagogical impact on teaching?* The sample consisted of eight academic staff, from different disciplines, who have used EVS in their lectures – only two of these were mathematics staff. The methodology was predicated on a mixed-methods approach and consisted of a blog, observations, survey, and follow-up interviews to clarify survey responses with some of the respondents.

The findings indicate that the participating staff generally see EVS as a useful teaching tool, with some having adapted their teaching methods based on feedback obtained from EVS use. The results show that EVS use can enhance student engagement, increase participation in class, give lecturers valuable feedback on student understanding, make the classroom more 'fun', and enable lecturers to change teaching practice and curriculum in response to student feedback. However, there are technical and pedagogical issues to be overcome to realise the full potential of EVS. Further, the two mathematics staff polled seemed to be ambivalent about the effectiveness of EVS for Mathematics modules.

This study has been written up as a journal article (i.e. King & Robinson, 2009c).

Staff Focus Group (2008) Study

The aim of the study was to evaluate, based on 'expert' feedback, whether question structure influences the type of learning approach i.e. surface or deep that students adopt towards answering questions. The sample (i.e. experts) consisted of six staff from the MEC who had mathematics teaching experience ranging from 12 to 35 years. These experts were invited to discuss and provide feedback on the learning approach affordance of eight algebra questions (see Appendix H) during a 70-minute focus group session. These questions, which I created myself, were set at GCSE/A level standards and comprised the topics, BODMAS, sequences and series, and linear equations.

The findings indicate that there was a lack of consensus from the participants i.e. experts about whether a question elicited a surface or deep approach, from the instructional design perspective. One participant commented that the session provided 'fascinating insight into difficult thought processes going on in different ways of tackling the same problem….So you could imagine that your class would have different thought processes going on in there'. Another participant observed, 'and we even struggled today to say which of the questions are conceptual and procedural, haven't we?' In addition, pre-session and post-session comparisons of participant responses to the question, What percentage (%) of (engineering/pure) maths teaching should be procedural or conceptual? revealed significant shifts in all but two of respondent submissions. One staff member moved towards a more procedural approach while two moved towards a weightier emphasis on the conceptual approach.

But there was broadly a consensus that the approach elicited would depend on the aims or learning objectives for using specific questions, and also on individual

student responses. One participant commented that the type of learning approach a question would elicit would depend on 'where I am and what my aims are. If I'm introducing a concept – mainly conceptual; if I'm reinforcing a skill there will be a procedural element'. Another commented, 'I still find it hard to say a question "is" procedural etc., because it depends [on] how an individual reacts to it'.

There was also some agreement that the type of approach adopted by students to solve a problem would depend on the quantity of instruction previously received on the subject. Further, one participant highlighted the importance of procedural fluency as a precursor to conceptual understanding: 'Now, I feel, when I talk about skills, I'm getting something that's more procedural, um, but behind all the skills, there are concepts'. The session also highlighted how instructors' assumptions about students' levels of knowledge are often not grounded in reality. This was because one participant thought that Q4 (Figure 1.3) would pose no problems for students. However, another participant countered this assertion with evidence that some students actually struggled with answering Q4 correctly. The influence of question types on student learning approaches would be investigated in this thesis (see Section 1.6).

Figure 1.3 Q4: A question on linear equations which some students found difficult.

Student Focus Group (2008) Study

The aims of the study were to investigate student learning approaches to algebra, and to evaluate the impact of using EVS (algebra) questions on student engagement. The sample consisted of 11 first-year Sports Technology students (class size n=25). Seven

of these had taken A-level mathematics, while the other four had taken mathematics up to GCSE level only. So there was a gap in the pre-entrance qualifications of the sample. The study method consisted of two focus group sessions with the A level students in one group, and the other consisting of the GCSE students, plus one student with an A level qualification. Each focus group lasted for about 70 minutes. The procedure adopted for the conduct of the focus group sessions is similar to the interview protocol described in Chapter Three of this thesis. In fact, these focus group sessions served as a pilot for the interview study presented in Chapter Three. So during the focus group sessions, students were asked general questions about their intentions/strategies for learning algebra on the module. They were also asked specific algebra questions, which consisted of some EVS questions, which had been used in lectures. I created some of these questions, but the instructor created the majority of the questions (see Appendix I for the questions).

The findings indicate that the two groups differed somewhat in their approach to problem solving. The GCSE group generally needed more time to answer questions. I also observed that their proficiency and confidence levels at answering questions were not at the same level as those of the A level group. Further, students in both groups appeared to have difficulties in solving problems involving fractions and negative values. In addition, students in both groups got questions wrong in the sessions, which they had also got wrong in class. This seemed to indicate that they did not address gaps in their understanding, as exposed through EVS use – a concept explored in Chapter 4.5.4.

The findings also indicate that the students perceived EVS as being helpful in engaging them with learning mathematics on the module. However, I could not characterise individual student approaches to learning due to the group nature of the responses. It was also not possible to probe individual responses due to the focus group format. This was one reason I designed one-on-one interviews, as described in Chapter Three.

Staff Survey (2009): US Staff Experience of Using Electronic Voting Systems

The study was designed to answer the research question, How has the use of EVS influenced the teaching of university mathematics in the US? The sample consisted of 27 US-based academic staff who have used or are currently using EVS to teach mathematics in universities (It should be noted that although only 27 staff completed the survey, no one knows what the population of users of EVS for mathematics

instruction in the US is. In fact, my survey is the first to attempt this task. Also, a similar survey was conducted in the UK, and will be presented in Chapter Two – see Section 1.6). These academics were identified through a similar process to the one described in Chapter 2.2.3. The identified staff were then invited to complete an online survey similar to the one described in Chapter 2.2.1.

The findings indicate that 81.5% (i.e. 22) of the staff polled view EVS as a tool that can significantly enhance the teaching of university mathematics. However, five staff (i.e. 18.5%) were unsure or undecided about the utility of EVS for mathematics teaching. Secondly, staff responses also indicated that the most beneficial impact of EVS use on their teaching is the 'identification of student misconceptions and/or errors', and 'increased lecturer-student interactivity' in their lectures. A related finding was the fact that the most cited benchmark for the evaluation of the effectiveness of an EVS question was when student response 'led to the identification of problem areas'. Further, seven staff (25.1% of respondents) indicated that EVS use had contributed to an improvement in overall academic performance in their classes. However, no data was provided on how this outcome was assessed, as the survey was not designed to capture this.

Feedback Survey (2009) Study: Gauging Student Understanding of Module Content
The aim of the study was to answer the research question: How effective are the methods being used by academic staff to gauge student understanding of (mathematics) lecture material i.e. course or module content? The sample consisted of 46 academic staff from various universities across the UK. These instructors were required to complete an online survey. In the survey, they were presented with a list of 19 methods for gauging student understanding of module content, and were asked to rate these methods based on their perceived (low, medium or high) usefulness for gauging student understanding.

The findings indicate that the methods rated as being the most useful for gauging student understanding are (in descending order): Examinations, individual consultations with students, students asking questions in lectures without being prompted by the instructor, marking of problem sheets, end-of-module student feedback (forms), small group tutorials (n<20), and (paper-based) coursework. Of these seven, only coursework and small group tutorials have the potential to provide instructors with regular feedback, on a critical mass scale, about student progress and/or difficulties with related module content. Computer-based coursework, large group tutorials (n>20),

peer assessment, group projects, and seminar presentations were rated as not being very helpful means for receiving feedback about student understanding. Further, staff indicated that they would consider adopting other feedback methods. The four most cited factors that staff indicated they would consider in evaluating whether to adopt other methods are evidence from the (UK) mathematics community about the method's reliability, as well as the ease, time required, and cost of implementing the method(s). In the next section, I will present the studies which are included in this thesis.

1.6 THESIS OUTLINE

The studies which are presented in this thesis were conducted to provide answers to the research questions enumerated in Section 1.4, with the thesis chapter corresponding to each research question highlighted. This thesis consists of seven chapters (including this chapter) and in this section, I will present descriptive overviews of the remaining six chapters.

Chapter Two: Staff Views on the Use of Electronic Voting Systems for Teaching Mathematics

This chapter is about the use of EVS to enhance the teaching of university mathematics. Therefore, academic staff who have used or are currently using EVS to teach mathematics in universities across the UK were surveyed in order to assess the impact of EVS use on mathematics teaching and learning. This study was undertaken to provide insights into the research question, How has the use of EVS influenced the teaching of university mathematics?

The contents of Chapter Two are as follows: The background to the study is presented, and this is followed by the presentation of a theoretical framework to explain the impact of EVS as described in research literature. The study methodology, including the analytical procedures and the validation measures employed, is then presented. This is followed by the presentation and analyses of the survey results, with the conclusions presented afterwards.

Chapter Three: Qualitative Research Methodology

To answer Research Questions 2 and 3, I designed a qualitative research study (Bryman, 2008:369), consisting of one-on-one interviews with students, whereby I

investigated the impact of EVS use on mathematics learning, using the MAB104 (engineering mathematics) module at Loughborough University as my unit of analysis. Further, the interview data is supplemented by documentary evidence from the intended learning outcomes' specification for the module, the module assessment structure, and application of a multi-theoretical framework i.e. theories of learning in the interpretation of data. Chapter Three is therefore a presentation of the *methodology*, including the *analytical techniques* and *reliability/validity* measures I adopted for the interview study. The study results will subsequently be presented in Chapters Four, Five and Six.

Chapter Four: The Impact of the Use of Electronic Voting Systems on Student Engagement

In Chapter Four, I present evidence on how EVS use has influenced student engagement with respect to mathematics learning. The findings presented in this chapter are based on analysis of data with respect to the research question, How has the use of EVS impacted (or otherwise) *student engagement* with respect to the learning of mathematics at university?

The chapter begins with background information on the role and types of student engagement in learning. This is then followed by a presentation of how EVS use has influenced the three dimensions of student engagement earlier presented i.e. emotional, behavioural and cognitive engagement. Then there is a section which focuses on a brief enumeration of the disadvantages of EVS use, and then the discussion/concluding section about the interconnectedness of the three different strands of student engagement is presented.

Chapter Five: Characterising Student Approaches to Learning

The purpose of Chapter Five is to answer the research question, What is the student's approach to learning mathematics? The aim is to characterise student approaches, at the course level, to learning mathematics on the module being investigated, based on evidence from interviewee transcripts. To undertake these characterizations, I utilised Marton and Saljo's (1976a), approaches to learning theory (ALT), framework. To provide alternative views of student learning approach characterization, I also employed goal theory (e.g. Pintrich, Conley & Kempler, 2003), and the three worlds of mathematics framework (Tall, 2008). My goal is to characterise individual interviewees as to whether they exhibit a surface or deep approach to learning mathematics. This

investigation is qualitatively different from that presented in Chapter Six i.e. an evaluation of how the use of EVS questions has influenced student approach to learning mathematics on the module being investigated.

Chapter Five begins with the presentation, related literature review and rationale for the adoption of the multiple theoretical frameworks that I have employed, in primary and secondary analyses, to characterize student approach to learning mathematics. Then I briefly introduce the analytical framework and strategies I used in analysing interviewee transcripts, with a view to characterising individual student learning approaches. This is followed by the data presentation and subsequent characterisations of the approach to learning mathematics of four selected interviewees (I could not present data for all 10 interviewees due to space constraints). These four were selected because their learning approach characterisations represent a whole spectrum of learning approaches that I would like to highlight. The chapter concludes with a discussion of the interrelationships between the different theoretical frameworks employed for characterising student learning approaches, and the implications for mathematics learning.

Chapter Six: The Impact of the Use of Electronic Voting Systems' Questions on Student Learning Approaches

In Chapter Five, I present student learning approaches at the *course* level, using a multiple theoretical framework. In contrast, in Chapter Six, I present evidence on how the use of EVS questions has influenced student learning approaches at the *task* level. The distinction is that how students approach a task e.g. question or problem is not necessarily the same as the one they adopt at the whole course or module level (e.g. Case & Marshall, 2004). However, student learning approaches will be presented from the approaches to learning theoretical framework only. The results presented are based on the analyses of interviewee transcripts and are designed to answer the research question, How has the use of EVS questions influenced (or otherwise) student approach to learning mathematics?

The structure of this chapter is that I first present the course context for the mathematics module from which the interviewees were drawn. This is then followed by a description of the pedagogical context in which EVS questions are used, which I refer to as formative teaching. Then I present evidence or indications of how the use of EVS questions have impacted student learning approaches. In the next section, I discuss how the use of calculators influences student learning approaches, especially with respect to

problem solving or (the acquisition of) procedural fluency. This is then followed by a consideration of how the use of guesswork influences student approach to learning, particularly in regard to the use of EVS questions, and the implications of guesswork adoption for student learning.

Chapter Seven: Discussion and Conclusion

In Chapter Seven, I will present a review of the main findings of the studies presented in Chapters Two to Six. This will then lead to a discussion and synthesis of selected findings and themes which are germane to elevating understanding on the role of EVS to impact mathematics teaching and learning. This will then be followed by a list of recommendations that are grounded in the synthesis of the findings reported. I will then highlight the contributions of the research presented in the thesis to the body of knowledge on the role of educational technologies in mathematics teaching and learning. Then I highlight topics or areas of interest which future research can address. I will then conclude the thesis by presenting concise answers to the research questions (see Section 1.4).

CHAPTER TWO

STAFF VIEWS ON THE USE OF ELECTRONIC VOTING SYSTEMS FOR TEACHING MATHEMATICS

2.1 INTRODUCTION

This chapter is about the use of EVS to enhance the teaching of university mathematics. Therefore, academic staff who have used or are currently using EVS to teach mathematics in universities across the UK were surveyed in order to assess the impact of EVS use on mathematics teaching and learning. This study was undertaken to provide insights on the research question, What are the views of academic staff using EVS on the impact of the technology on their teaching of university mathematics?

The main contribution of this study is that it is the first of its kind to present and describe the views and observations of academic staff, from various institutions, on the impact of EVS as a tool for university mathematics teaching. Research studies on EVS, apart from the invited contributions to books, have largely consisted of descriptions of research on EVS within specific institutional contexts. In contrast, this study presents evidence of EVS effectiveness for mathematics teaching from staff working in 14 different institutional contexts and requirements. These types of studies are required in order to adequately assess the evidence (e.g. Sloane, 2008) on EVS usefulness for mathematics teaching and learning.

The outline of the rest of this study is as follows: The background to the study is presented, and this is followed by the presentation of a theoretical framework to explain the impact of EVS as described in research literature. The study methodology, including the analytical procedures and the validation measures employed, is then presented. This is followed by the presentation and analyses of the survey results, with the conclusions presented afterwards.

2.1.1 BACKGROUND

EVS systems are an ubiquitous presence on university campuses in the US, a phenomenon which Abrahamson (2006) described thus:

Today, at almost every university in the USA, somewhere a faculty member in at least one discipline is using a response system in their teaching. This is a phenomenon that has mushroomed to its present stage, mainly within the past three years, from a mere handful of pioneering educators a decade ago. *(p2)*

In the UK, there are at least 47 universities with an EVS presence[8]. As a result of the widespread interest, a number of publications – including three books (Bruff, 2009; Banks, 2006 & Duncan, 2005) have been produced on EVS. These publications largely consist of descriptions of EVS implementations in specific institutional contexts (e.g. Cline et al., 2007; Bode et al., 2009; Blodgett, 2006; Butler, 2005) and also to support specific approaches (e.g. Mazur, 1997; Hake 1998, Beatty et al., 2006), although a few of these are reviews (e.g. Caldwell, 2007, Simpson & Oliver, 2007; Fies & Marshall, 2007). Many of these publications are overwhelmingly positive on the impact of EVS use on teaching and learning in tertiary education. However, recent studies have also highlighted the potential drawbacks of using EVS, including the cost to students and institutions and the lack of (any significant) learning benefits accruing from EVS use (e.g. Bugeja, 2008; Johnson & Robson, 2008; Socol, 2008; Groveman, 2008).

In general, research literature indicates that EVS use offers three significant benefits. The first is reported learning gains, partly as a result of EVS use, especially in the peer discussion mode. However, most articles do not present evidence of this benefit. The second benefit is increased student engagement – this includes increased student participation in lectures, enhanced interactivity in lectures and improvement in cognitive engagement with learning material. Bruff (2009) provided a rationale for this when he stated that:

Clickers provide each student with a chance to think about and respond to a question before hearing other students' answers. This opportunity for independent thinking can engage students more fully with a question by encouraging students who might typically wait to hear their peers' responses before seriously considering a question to think about a question on their own'. *(p199)*

---

[8] http://www.psy.gla.ac.uk/~steve/ilig/people.html

The third benefit is that the constant feedback produced during EVS use not only presents instructors with a relatively accurate and timely information about student comprehension, this also allows instructors to change the pace or content of lecture delivery to as to accommodate student needs. One experienced EVS user (Boyle, 2006) commented on this attribute of EVS use when he reflected that:

Audience response systems have changed the classroom. Those of us who use them could not return to the conventional lecture – you get "hooked" on interpreting the feedback and finding out what is going on in students' minds – and it is different every year.   *(p302)*

2.1.2 CONVERSATIONAL FRAMEWORK

A useful means of explaining the impact of EVS on teaching and learning is the application of the *conversational framework* (Laurillard, 2002, 2008) to the analysis of EVS use in lectures (Cutts et al., 2004; King & Robinson, 2009a).

    In the framework (Figure 2.1), 'Teacher's Ideas' represent an instructor's current knowledge of a (specific) topic. Similarly, 'Learner's Ideas' represent current student understanding and prior knowledge of a topic. The 'Practice Environment' is depicted by the use of EVS to present questions in lectures, which students have to answer, and on which instructors then provide feedback. The 'Learner's Practice' is depicted by students answering the EVS questions and often correcting mistakes, based on instructor feedback, after getting a question wrong initially.

    A core proposition of the framework is that real learning occurs when the teaching and learning process is a *dialogue*, a three-way, instructor-student, student-instructor and student-student communication loop between instructor and students. Classroom observations indicate that this three-way dialogue is facilitated through EVS use. An instructor presents a question during a lecture which students answer. Moreover, students are also regularly encouraged to discuss their answers with their peers, thus setting up peer interaction. Meanwhile, the conventional mathematics classroom typically features the instructor-student communication loop.
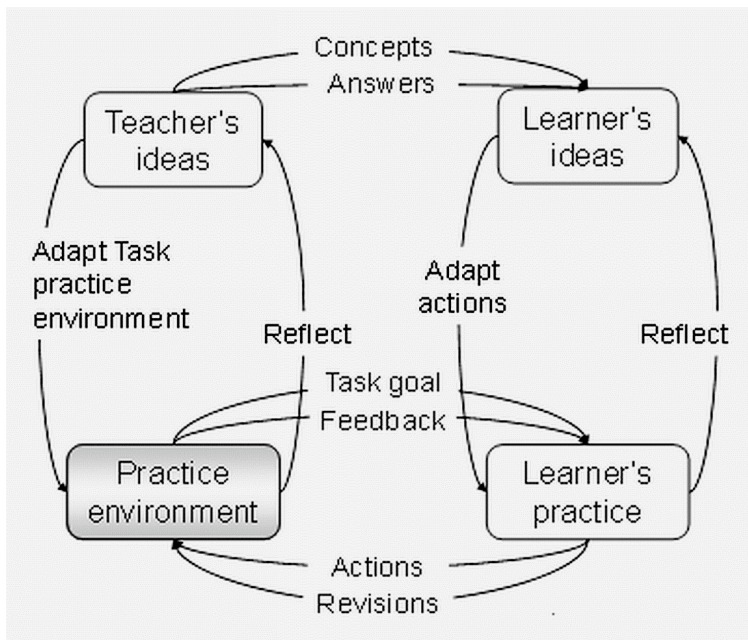
Figure 2.1 A modified version of Laurillard's conversational framework for evaluating educational technologies (Laurillard, 2008).

The three-way communication channel afforded by EVS use and illuminated by the framework is therefore a way of explaining why EVS has continually been cited as promoting increased student engagement. Further, feedback from students enables regular updates of teacher's ideas (a component of this is an instructor's knowledge or assumptions about the capabilities of a specific student cohort) based on how students answered a question i.e. student feedback. A real time or outside-the-lecture reflection on this experience might induce an instructor to *adapt* the lecture and the EVS questions used to better accommodate student needs, as identified through EVS use.

Similarly, instructor feedback after a question and answer session might induce a student to *reflect* on and *adapt* his/her ideas about the subject in question, often as a result of getting a related question wrong. This could then lead to *enhanced learner's practice* (i.e. problem solving or conceptual understanding fluency, as indicated by the learning gains demonstrated through the studies (Crouch & Mazur, 2001; Hake, 1998, etc).

In essence, the conversational framework provides an expedient theoretical framework for explaining the impact of EVS on mathematics teaching. In Chapter Seven, I will employ the framework to explain some of the findings about EVS use in relation to learning gains. Meanwhile, in the next section, I will present the methodology together with the methodological procedures adopted for the study

described in this chapter.

2.2 METHODOLOGY

The study described in this chapter employed a cross-sectional research design i.e. the 'collection of data on more than one case…at a single point in time in order to collect a body of quantitative or quantifiable data…,which are then examined to detect patterns of association' (Bryman, 2008, p44). Further, I adopted survey research, a type of cross-sectional research design (Bryman, 2008, p46) as the main data collection method. I decided to use a survey because it provided the best *fit-for-purpose* (Cohen, Manion & Morrison, 2007, p501) with respect to answering the research questions. This is why the survey type employed is *descriptive survey* research because this type of inquiry enables a researcher to 'look at individuals, groups, institutions, methods and materials in order to describe, compare, contrast, classify, analyse and interpret the entities and the events that constitute their various fields of inquiry' (Cohen, Manion & Morrison, 2007, p205). The adoption of descriptive survey research therefore enables me to collect data and to *describe, compare, contrast, classify, analyse and interpret the findings* with respect to how staff in the UK use EVS to enhance the teaching and learning of university mathematics.

2.2.1 METHOD

The main data collection instrument was a self-completion questionnaire (Bryman, 2008, p165), which was administered over the web. Web surveys were viewed as the most effective way of administering a survey to staff spread across the UK. Web surveys also have other benefits such as ease of access and use, reduced cost, and utility (Cohen, Manion & Morrison, 2007, p229). The surveys were administered via the Bristol Online Surveys (BOS)[9], which is proprietary software developed by the University of Bristol. I adopted a *semi-structured questionnaire* because this survey data collection instrument enables a researcher to set the agenda without presupposing the nature of the response (Cohen, Manion & Morrison, 2007, p321), as opposed to the use of a strictly close-ended questionnaire. So I interspersed closed questions with

---

[9] https://www.survey.bris.ac.uk/

open-ended items, and respondents were also able to clarify their submissions to close-ended questions. However, I limited the use of open-ended questions to make it easier for respondents to complete the survey. The survey had 34 items in total; 12 of these were open-ended items (three of these required very brief responses), and the rest were closed questions, which often had an 'other' box which respondents could use (and often used) to 'briefly' explain their selections (see Appendix A for questionnaire).

2.2.2 SAMPLE

The sample consisted of academic staff in the UK who have used or currently use EVS to teach mathematics to undergraduates. The sample consisted of four female and 12 male academics. The teaching experience of these academics in teaching university mathematics ranged from two to 33 years. The mean experience was 14.86 years while the median was 15 years (Table 2.1a).

Years of Experience	1-4	5-9	10-14	15-19	20-25	25+
No. of Respondents	3	1	3	4	4	1

Table 2.1a The university maths teaching experience of the survey respondents.

The experience of the respondents in using EVS ranged from having used EVS only once to using EVS regularly for more than three years. Ten respondents had used EVS regularly for at least two years, two had used the systems regularly for an academic year or semester, and four had used EVS on not more than three occasions. Further, the mathematics subjects taught with EVS ranged from Engineering Maths, Further Calculus and Matrices, Linear Algebra (tutorials) and Introduction to Pure Maths to Mathematics for Mechanical Engineers, Complex Analysis and Numerical Analysis. The level of students ranged from pre-university i.e. Foundation Year to Third (i.e. Final) and Fourth year (e.g. final year for engineering students and students under the Scottish system).

Correlation of Maths Teaching Experience and EVS Experience	1-4	5-9	10-14	15-19	20-25	25+
Have used EVS only once	1	---	1	---	--	--
Have used EVS 2-3 times	1	---	1	---	---	---
Have used EVS regularly for an academic semester	---	---	---	1	---	---
Have used EVS regularly for an academic year	1	---	---	---	---	---
Have used EVS regularly for 2-3 years	---	1	1	1	3	1
Have used EVS regularly for >3 years	---	---	---	2	1	---

Table 2.1b A correlation of university mathematics teaching experience (in years) with EVS usage.

A cross-tabulation of respondent university mathematics teaching experience (in years) with experience using EVS shows that of the 12 respondents with at least 10 years university teaching experience, only three have not used EVS for at least two years (Table 2.1b). Further, of the nine respondents with at least 15 years teaching experience, only one had not used EVS for at least two academic years.

2.2.3 RECRUITMENT

Academic staff using EVS to teach university mathematics were identified through several strategies. Through the information provided on a site[10] dedicated to providing information on all UK universities with an EVS presence, I identified and emailed the contacts listed on the site to inquire whether EVS was being used to teach mathematics at the respective institutions. Second, this same request (for identification for staff using EVS to teach mathematics) was sent to all mathematics departments in the UK via the Maths, Stats and Operational Research (MSOR)[11] network, a Subject Centre of the

---

[10] http://www.psy.gla.ac.uk/~steve/ilig/people.html

[11] http://www.ltsn.gla.ac.uk/

(UK) Higher Education Academy. Third, the request was also sent out to all the heads of departments of mathematics in the UK via a dedicated mailing list. Fourth, the request was sent out through another mailing list dedicated to EVS users in the UK.

From these strategies, 20 academic staff were identified as using EVS to teach mathematics i.e. this is the *population*, as far I was able to ascertain. I then sent an email in April/May 2009, towards the end of the academic year, to these individuals inviting them to complete the web survey, with the link to the survey included in the email. Sixteen staff eventually responded i.e. 80% of the population completed the survey. Although I sent at least one reminder to those who did not respond, their unresponsiveness had to be accepted in good faith because the survey was entirely voluntary. Moreover, three of these four staff who did not complete the questionnaire provided me with valuable comments about their use of EVS through email and informal conversations.

2.3 DATA ANALYSIS

The data collected consisted primarily of nominal (or categorical), and ordinal variables (Bryman, 2008, p321), and 'word-based data' (Cohen, Manion & Morrison, 2007, p322) from the open-ended questions. These are classified as non-parametric data which consequently are only amenable to univariate and (limited) bivariate analytical techniques (Bryman, 2008, p322), which provide descriptive statistics (Cohen, Manion & Morrison, 2007, p503). The techniques I adopted in analysing survey data include frequency tables (e.g. percentages), diagrams (bar charts, etc), measures of central tendency, and contingency (correlation or cross-tabulation) tables (Bryman, 2008, pp322-327; Cohen, Manion & Morrison, 2007, p506).

These techniques are to a large extent built into the BOS system, as results are automatically presented as frequency tables, appropriate to the dataset. This is possible because the BOS system makes use of five question types (Cohen, Manion & Morrison, 2007, p322): Multiple Choice – respondents may only select one answer (e.g. Table 6.13); Multiple Answer – respondents may select one or more answers (e.g. Table 6.8); Selection List – respondents may select only one answer from a drop down box; and Grid questions which are nested items with a higher level of complexity than the other types. The BOS system aggregates respondent submissions such that the answers are automatically transformed into frequency tables. For example, here is the frequency

table produced for the item, 'which of the following accurately describes your experience with EVS use?' (Table 2.2):

Have used EVS only once:		12.5%	2
Have used EVS 2-3 times:		12.5%	2
Have used EVS regularly for an academic semester:		6.2%	1
Have used EVS regularly for an academic year:		6.2%	1
Have used EVS regularly for 2-3 years:		31.2%	5
Have used EVS regularly for >3 years:		18.8%	3
Other (please specify):		12.5%	2

Table 2.2 Respondent experience in using EVS for mathematics teaching.

The BOS system also provides a facility to analyse the relationship between any pair of variables or datasets. For instance, here is a cross-tabulation showing the relationship between EVS use and perception of EVS usefulness for mathematics teaching (Table 2.3).

Cross Tabulation

Results are cross tabulated by question "3. Which of the following accurately describes your experience with EVS use?"

32. Based on my experience, EVS is a tool that can significantly enhance the teaching of university mathematics.	Have used EVS only once	Have used EVS 2-3 times	Have used EVS regularly for an academic semester	Have used EVS regularly for an academic year	Have used EVS regularly for 2-3 years	Have used EVS regularly for >3 years	Other	Totals
Strongly agree	0	0	0	0	2	2	0	4
Agree	2	1	1	1	3	1	2	11
Undecided	0	0	0	0	0	0	0	0
Disagree	0	0	0	0	0	0	0	0
Strongly disagree	0	1	0	0	0	0	0	1
Totals	2	2	1	1	5	3	2	16

Table 2.3 A correlation of EVS experience with perception of EVS usefulness for university mathematics teaching.

The word-based data from the open-ended questions were analysed using thematic analysis (Bryman, 2008, p554). For example, six themes or categories were identified as the barriers to EVS use based on respondent comments (this is presented later in this

chapter). I have also indicated, where appropriate, the number of times a comment occurs (often by using the term recurring frequency). This was done to provide implicit quantification, in order to minimise a qualitative research reporting bias known as *anecdotalism* – reports that give 'the reader little guidance as to the prevalence of the issue to which the anecdote refers' (Bryman, 2008, p599).

2.4 RELIABILITY, REPLICABILITY AND VALIDITY

To ensure that the findings of a study are credible and capable of being generalised to similar demographics, quantitative researchers often adopt multivariate techniques (e.g. Cronbach's alpha) to establish the reliability and validity of their studies. Since my data consisted of non-parametric data, I had to find other credible means of establishing the reliability, replicability and validity of this study. Based on the recommendation (Bryman, 2008, p153) that there are 'a number of different ways of investigating the merit of measures that are devised to represent social scientific concepts', I employed a number of measures as a means of validating this research study. The following section describes some of the measures I adopted to establish the reliability, replicability and validity of this study:

- Survey Pilot
- Face Validity and Reliability
- Internal Validity (Respondent Validation)
- Replicability/External validity
- Instrument Structure and Item Corrections
- Ethics

2.4.1 SURVEY PILOT

The survey instrument used in the study has undergone *two piloting cycles*. The survey instrument is based on a previous instrument that was piloted (together with a separate feedback questionnaire), and administered in 2008 for an explorative study, with the results of the study published as (King & Robinson, 2009c). The current survey includes 18 items from the 2008 instrument, which was itself an adaptation and significant extension of a survey instrument administered at Glasgow University[12]. The

---

[12] Dr. Margaret Brown gave permission for the reuse of the items.

current survey was piloted with two academic staff members, with one in Germany and the other in the UK. The former had only used EVS less than five times while the latter had used it 'regularly for an academic semester'. As a result of the pilot and face validity measures (described below), I effected changes to at least 16 of the 33 survey items in the pilot instrument. A few of these changes will be highlighted later under the Instrument Structure and Item Corrections section.

2.4.2 FACE VALIDITY AND RELIABILITY

As part of **face validity** measures, the initial drafts of the survey instrument were submitted to two members of academic staff with statistical expertise who provided useful comments. The draft instrument was also submitted to three members of the research panel (including my supervisor) who also provided corrective feedback. Further, feedback from this panel helping me to audit the initial reports of the findings to ensure that the *process* (i.e. steps, methodologies, etc) adopted for the research investigation was grounded in established norms of good practice, and that the *product* (or findings) was grounded or commensurate with the data presented as evidence (Lincoln & Guba, 1985, p318). This auditing procedure was undertaken to ensure the reliability and objectivity of the study (Lincoln & Guba, 1985, p317).

Further, Cohen, Manion and Morrison (2007, p146) stipulated that a 'reliable instrument for a piece of research will yield similar data from similar respondents over time'. Respondent submissions to similar items in the 2008 survey pilot, 2008 survey, 2009 survey pilot and 2009 survey (i.e. the current survey) share many commonalities. This might be viewed as a measure of the consistency or reliability of the instrument over time.

2.4.3 INTERNAL VALIDITY (RESPONDENT VALIDATION)

To minimise invalidity or ensure internal validity (which I could not determine from advanced statistical techniques due to the non-parametric nature of my data), I employed respondent validation, suggested as a measure of the validity of quantitative research (Cohen, Manion & Morrison, 2007, p145). This criterion is viewed as being 'satisfied when source respondents agree to honour the reconstructions' (Lincoln & Guba, 1985, p329) provided by the researcher. To implement respondent validation, I emailed all respondents with a copy of their individual submissions to the survey questions (the BOS systems facilitates this). I also sent them a draft of my findings and

interpretations, which I asked them to corroborate or object to as appropriate (see Appendix B for a sample letter). Subsequently, I incorporated useful suggestions from the feedback I received.

2.4.4 REPLICABILITY/ EXTERNAL VALIDITY

This criterion is a measure of 'an investigation's capacity to be replicated' (Bryman, 2008, p32). Bryman also suggests that replicability may be established by outlining the procedures for the research investigation adopted in sufficient detail. This includes providing information on: 'selecting respondents; designing measures of concepts; administering research instruments; and analysing data' (Bryman, 2008, p45). I have attempted to satisfy this requirement by providing relevant information under the methodology section and elsewhere in the report.

Further, I think the findings of the study are generalisable as the sample is representative i.e. 'sample that reflects the population accurately so that it is a microcosm of the population' (Bryman, 2008, p168) of the *population* of UK academic staff using EVS to teach university mathematics.

2.4.5 INSTRUMENT STRUCTURE AND ITEM CORRECTIONS

In this section I would illustrate, with appropriate examples, the kind of changes I made to the survey instrument due to feedback from the validation measures outlined above. I would also outline how particular attention was paid to the content, sequencing and structure of the instrument to minimise invalidity.

9. In your view, how many EVS questions should be used per lecture?			
1-2:		0.0%	0
2-3:		0.0%	0
4:		0.0%	0
More than 4:		0.0%	0
Depends on the purpose and time available for lecture:		100.0%	2

Table 2.4 Pilot instrument showing prescriptive question wording and overlapping answer options.

9. How many EVS questions do you typically use per lecture?			
1-2:		6.2%	1
3-4:		6.2%	1
5-6:		25.0%	4
>6:		31.2%	5
Other (please specify):		31.2%	5
View All Responses - There are too many responses to display on this page and so all the responses to this question are available on a separate page.			

Table 2.5 Main instrument showing descriptive question wording and answer options that do not overlap.

EXAMPLE 1: In the example above, I changed the question wording in the pilot instrument (Table 2.4) from being *prescriptive* (i.e. the use of 'should') to *descriptive* in the main instrument (Table 2.5), which respondents would find easier and be able to answer more accurately. I also changed the overlapping answer options in the pilot to options that do not overlap.

EXAMPLE 2: In the example below, I removed the option, 'depends on the goal for asking the question' (Table 2.6), from the main instrument (Table 2.7) because the selection of that option was not helpful, as there was the tendency for respondents to select this option. In the 2008 pilot and also in the 2008 instrument, most of the respondents had selected this option. Bryman (2008, p247) recommends that 'if everyone or (virtually everyone) who answers a question replies in the same way, the resulting data are unlikely to be of interest because they do not form a variable. A pilot study allows such a question to be identified'.

13. How do you evaluate whether a question has been effective?			
When there is good spread in terms of the range of student response:		n/a	1
When more students get the answer right:		n/a	0
When more students get the answer wrong:		n/a	0
When student response leads to the identification of problem areas:		n/a	1
When student response produces unexpected results:		n/a	0
Depends on the goal for asking the question:		n/a	1
Other (please specify):		n/a	1
My questions were not based on prior instruction and no calculations were required to be done. It was an attempt to show the group the range of possible outcomes that would result from an untrained approach to probability. In this regard substantially different answers suited my purpose – and were expected.			

Table 2.6 Pilot instrument with the option, 'depends on the goal for asking question'.

13. How do you evaluate whether a question has been effective?			
When there is good spread in terms of the range of student response:		n/a	4
When more students get the answer right:		n/a	4
When more students get the answer wrong:		n/a	1
When student response leads to the identification of problem areas:		n/a	12
When student response produces unexpected results:		n/a	5
Other (please specify):		n/a	10
View All Responses - There are too many responses to display on this page and so all the responses to this question are available on a separate page.			

Table 2.7 Main instrument without the answer option, 'depends on the goal for asking question'.

EXAMPLE 3: In the example below, comparison of the item options in (pilot – Table 2.8)) with (main instrument – Table 2.9), shows that the latter has a much more defined order, such that it makes it easier for respondents to rate student attitudes towards EVS use.

19. How would you say students have responded to the use of EVS?			
They have embraced it enthusiastically:		n/a	0
Their reaction has been mixed:		n/a	0
Their enthusiasm has dwindled:		n/a	0
Other (please specify):		n/a	2

Table 2.8 Pilot instrument showing answer options as ordinal data, with relatively poor ordering.

20. How would you say that students have responded to the use of EVS?			
They have shown very positive attitudes towards EVS use:		18.8%	3
They have shown positive attitudes towards EVS use:		68.8%	11
They have been indifferent towards EVS use:		0.0%	0
They have shown negative attitudes towards EVS use:		6.2%	1
They have shown very negative attitudes towards EVS use:		0.0%	0
Other (please specify):		6.2%	1

Table 2.9 Main instrument showing answer options as ordinal data, with a higher level of ordering.

42

EXAMPLE 4: The only difference between the pilot (Table 2.10) and the main instrument (Table 2.11) is that the latter has an 'other' column through which respondents were prompted (the prompt is not shown in the extract below as it is only available online) to clarify or explain their responses to the closed questions. This is an example of the utility of a semi-structured questionnaire, as this option would not be available in a typical structured questionnaire.

26. Could you describe the kind(s) of feedback you provide to students after they have submitted their answers to the EVS questions used in class?			
A step-by-step solution of the problem:		n/a	0
Explanation of why the alternative options provided are incorrect:		n/a	2
Highlight of question's importance to overall topic and course objectives:		n/a	0
Discussion of the distribution of students' correct and incorrect answers:		n/a	1

Table 2.10 Pilot instrument with answer options as they would appear in a typical structured questionnaire.

27. Could you describe the kind(s) of feedback you provide to students after they have submitted their answers to the EVS questions used in class?			
A step-by-step solution of the problem:		n/a	11
Explanation of why the alternative options provided are incorrect:		n/a	14
Highlight of question's importance to overall topic and course objectives:		n/a	8
Discussion of the distribution of students' correct and incorrect answers:		n/a	11
Other *(please specify)*:		n/a	4
View All Responses - There are too many responses to display on this page and so all the responses to this question are available on a separate page.			

Table 2.11 Main instrument showing how the flexibility provided in the answer options in a semi-structured questionnaire may lead to clarification of responses.

EXAMPLE 5: To mitigate acquiescence – the tendency for respondents to respond the way they think they are expected to respond (Cohen, Manion & Morrison, 2007, p151 – see Chapter 3.4.4 for more on acquiescence), double check results and assess the

consistency of responses, it is often advised that a questionnaire item be repeated in the same instrument but presented in different formats. Whereas the pilot instrument had only one question where respondents had to rate the EVS usefulness for mathematics teaching, the main instrument had two – and these are presented below (Tables 2.12 and 2.13). This is the reason why the pilot instrument had 33 items while the main one had 34. One of the items (item 18) is mid-way through the questionnaire, while the other is near the end. This was done deliberately due to sequencing requirements, which will be discussed later in this section.

18. Based on your experience, please rate the value of EVS as a tool for the teaching of university mathematics:		
Strongly advantageous:	31.2%	5
Advantageous:	50.0%	8
Undecided:	12.5%	2
Disadvantageous:	0.0%	0
Strongly disadvantageous:	6.2%	1

Table 2.12 Main instrument showing item on rating of EVS usefulness for mathematics teaching.

32. Based on my experience, EVS is a tool that can significantly enhance the teaching of university mathematics.		
Strongly agree:	25.0%	4
Agree:	68.8%	11
Undecided:	0.0%	0
Disagree:	0.0%	0
Strongly disagree:	6.2%	1

Table 2.13 Main instrument showing a similar item on rating of EVS usefulness for mathematics teaching.

SEQUENCE: Sequencing of questions is important as this may influence respondents' ability or attitudes towards completing a survey: 'The ordering of the questionnaire is important, for early questions may set the tone or the mindset of the respondent to later questions' (Cohen, Manion & Morrison, 2007, p336). The authors recommended that a questionnaire start with 'unthreatening factual questions', then move to 'closed questions' interspersed with open ended questions, and then end with more open ended questions (Cohen, Manion & Morrison, 2007, p337). Consequently, I created the survey instrument so as to observe this sequence.

QUESTION ORDER EFFECTS: A related construct to questionnaire sequencing is question order effects. This may be viewed as the 'possible implications of early questions on answers to subsequent questions' (Bryman, 2008, p204). This was one reason why survey item 18 (Table 2.12) came after items where respondents had to answer questions about the perception of EVS use as a time-consuming activity (item 14), and its potential to limit an instructor's ability to cover the required material in lectures (item 15). Item 32 (Table 2.13) was also placed near the end of the survey after respondents had responded to a variety of questions on EVS use. In fact, that section of the survey was labelled, 'reflection'. The question order was also the same for all respondents, which is in line with Bryman's recommendation that 'within a survey, question order should not be varied' (2008, p204).

PRIMACY EFFECT: To mitigate the primacy effect – the tendency for respondents to 'choose items that appear earlier in a list rather than items that appear later in a list' (Cohen, Manion & Morrison, 2007, p236, 336), I exclusively made use of Multiple Choice and Multiple Answer question types or presentation styles (see earlier). These question presentation styles as afforded by the BOS system enable respondents to see all options, whereas some options are often obscured in pull down or menu lists. Moreover, apart from one item, none of the survey items had more than seven answer options.

LAYOUT: Visual features are an essential component of the Internet survey experience, especially for respondents. Cohen, Manion and Morrison (2007, p230) recommends that attention be paid particularly to the use of 'emboldened words, large fonts, colours, brightness, section headings, spacing, placing boxes around items' to enhance survey readability and improve the user experience for respondents. The aim is to ultimately enhance the user or respondent experience in completing a survey. The BOS system provides most of these facilities (although not all as the fonts for the questions and answer options are by default the same). For example, I was able to structure the survey into the following five sections: Background, EVS Questions and Pedagogical Considerations, Student Experience, Feedback, Reflection. These sectional headings were used to group similar questions while separating these from the other sections. Prior to the pilot and as part of the changes effected in response to the peer audit (a measure for reliability), I changed the presentation style of an item from grid or nested to multiple-choice format (see Tables 2.14 and 2.15). The feedback was that the

grid style was unnecessarily complicated.

14. Compared to classes where EVS was not used, how much (extra) time did you spend collecting, designing or creating the EVS questions used in classes where EVS was used?	A great deal of time (i.e. significant extra time spent)	A moderate amount of time (i.e. extra time spent not very significant)	Minimal time increase (i.e. no significant difference in time spent)	Other (please specify)
a. Early in Semester	○	○	○	○
b. Later in Semester	○	○	○	○

Table 2.14 Questionnaire item in grid format.

14. Compared to classes where EVS was not used, how much (extra) time did

14.a. Early in Semester			
A great deal of time (i.e. significant extra time spent):		31.2%	5
A moderate amount of time (i.e. extra time spent not very significant):		25.0%	4
Minimal time increase (i.e. no significant difference in time spent):		0.0%	0
Other (please specify):		43.8%	7

View All Responses - There are too many responses to display on this page and so all the responses to this question are available on a separate page.

14.b. Later in Semester			
A great deal of time (i.e. significant extra time spent):		12.5%	2
A moderate amount of time (i.e. extra time spent not very significant):		50.0%	8
Minimal time increase (i.e. no significant difference in time spent):		18.8%	3
Other (please specify):		18.8%	3

View All Responses - There are too many responses to display on this page and so all the responses to this question are available on a separate page.

Table 2.15 Same questionnaire item in multiple choice format.

CHECKLIST: I used the checklist (Bryman, 2008, p249) to verify that the survey instrument creation, piloting, correction and administration were all undertaken based on best practises. Although I complied with most of the requirements in the checklist, there are still requirements that I might have wittingly left out or been unable to meet. For instance, Bryman recommended that leading and 'double-barrelled questions' should be avoided (Bryman, 2008, p242). However, I used a double-barrelled question, in fact a triple one (Table 2.16), so as to reduce the length of the survey on the screen, which was one of the issues that had been highlighted via the pilot.

Section 1: Background
1. Name (optional) / University / University Maths' Teaching Experience e.g. Samuel King / Loughborough / 5 years
View All Responses - There are too many responses to display on this page and so all the responses to this question are available on a separate page.

Table 2.16 A triple-barrelled question used in the survey to conserve space.

2.4.6 ETHICS

The completion of the web survey was entirely voluntary. None of the participants received any form of compensation or incentives to complete the survey. To ensure confidentiality, respondents are not indentified in the transcripts, and I have also employed gender-neutral descriptions in presenting excerpts. I also set up the survey such that respondents could access their data even after completing the survey so as to, for instance, effect changes during the period the survey was open. Further, apart from the University-appointed administrator for the BOS system, I am the only one who has access to respondents' data, thus ensuring respondent privacy. Data collection through the BOS system also complies with the eight principles or requirements of the (UK) Data Protection Act[13].

---

[13] http://www.survey.bris.ac.uk/support/faq/data-protection/what-are-the-eight-data-protection-principles

2.4.7 APPROPRIATENESS OF THE RESEARCH DESIGN/VALIDITY MEASURES EMPLOYED

As stated earlier, the respondents who participated in this study represent nearly the whole population of the study target. Based on the fact that the population is small, this question may arise, Is survey research methodology an appropriate choice for the study conducted? The answer to this question is yes. One reason for sampling is that either the (whole) population is not accessible, or there are practical constraints, such as time and money, that make a survey of a whole population impractical. So a social research survey based on nearly the whole population is ideal:

In an ideal world the researcher would be able to study a group in its entirety…. That is rarely possible nowadays because such groups are no longer isolated or insular. Hence the researcher is faced with the issue of sampling, that is, deciding which people it would be possible to select to represent the wider group.   *(Cohen, Manion & Morrison, 2007, p175)*

Second, it is important to clarify that surveys may be used for several purposes, especially as surveys are often associated with sampling (Bryman, 2008, p168), i.e. the perception is that surveys are mainly used to sample populations of interest. There are many types of survey research, such as *Analytic*, i.e. surveys that 'operate with hypothesized predictor or explanatory variables that are tested for their influence on dependent variables'; *Exploratory*, i.e. surveys 'in which no assumptions or models are postulated, and in which relationships and patterns are explored'; and *Confirmatory* surveys, 'in which a model, causal relationship or hypothesis is tested' (Cohen, Manion & Morrison, 2007, p207). The type I have adopted, *Descriptive* survey research, described in Section 2.2, is particularly useful for empirical investigations of (whole) populations (Cohen, Manion & Morrison, 2007, p207).

A related question that may be asked is, What is the purpose of detailing validity/reliability measures undertaken to validate this study, when nearly the whole population was sampled? First, reliability and validity measures 'are primarily matters relating to the quality of the measures that are to tap the concepts in which the researcher is interested, rather than matters to do with a research design' (Bryman, 2008, p44). This implies that measures, such as face validity – that a 'measure [e.g. a questionnaire item] apparently reflects the content of the concept in question' (Bryman, 2008, p152); cannot be assumed to be valid/reliable simply because nearly the whole population completed the survey.

Further, measures, such as survey piloting, respondent validation and minimisation of question order and primacy effects, are critical to establishing that the concepts being measured are 'tapped' appropriately, irrespective of whether a sample or a whole population completed a survey. An example of a cross-sectional survey that 'typically refers to the complete enumeration of all members of the population of a nation state' is the census (Bryman, 2008, p169). Although nearly the whole population of a given locality completes a census survey, yet the survey is usually piloted before the administration of the main census.

One limitation of this survey paradigm I adopted, is that I could not actively follow-up some of the respondent submissions that might have benefited from further clarifications. For example, I could have clarified respondent claims, through subsequent interviews (Section 2.5.2), the form and modalities through which EVS use was mandated as a departmental requirement. Perhaps there might be instances where EVS use is not mandated as a (blanket) policy, but it might nevertheless be perceived as such by some academic staff, based on salient contextual factors. Another example, is in Section 2.5.6, where I could have asked a respondent to describe the 'jamboree-like' class conditions that made him/her refrain from using EVS to facilitate peer discussion. This could have painted a clearer picture of the constraints within that particular context.

However, it should be noted that I did employ respondent validation – I sent all respondents the draft report of this chapter, as well as their individual survey submissions, and asked them to verify that I had accurately interpreted their submissions. I also asked them to make suggestions, where possible, on how the analysis and findings mat be strengthened. Two respondents subsequently responded with useful comments, which I employed to make necessary amendments.

2.5 PRESENTATION AND ANALYSIS OF RESULTS

In this section, the survey results together with related analyses would be presented under the relevant sub-sections. The sub-sections are not presented based on the questionnaire order indicated in Section 2.4.5 (i.e. Layout). The results are instead presented based on the premise that related themes from different sections of the

questionnaire should be presented together. This was done to ensure coherence and enhance the readability of the results.

2.5.1 TYPE AND OWNERSHIP OF EVS SYSTEMS

Seven of the respondents indicated that they used the InterWrite EVS system, six said they used Turning Point system, while two respondents had used Class Act and PP Vote systems[14]. One respondent could not recall the EVS system used. Moreover, only five respondents stated that they had used free text or numerical entry EVS systems. The implication of this is the question type most frequently used with EVS systems was multiple-choice questions (MCQs). Respondent submissions also indicated that neither students nor lecturers currently have to buy the EVS handsets. The handsets are provided either through a designated unit or department at a university or a loan scheme is operated whereby students borrow the handsets for a specified period for use in the requisite classes.

2.5.2 STAFF INTRODUCTION TO EVS

Respondent submissions to the item, 'How did you find out about EVS and what made you decide to start using it?' indicated that most of them i.e. 12 respondents became aware of EVS through a presentation or demonstration of EVS use at a conference/seminar, or through a colleague. The three excerpts below highlight this:

'Attended a learning and teaching conference where it was mentioned by one of the speakers, followed this up with research';
'Attended a short presentation. Looked interesting;'
'Colleague mentioned it to me (he'd only heard of it, not used it). Seemed perfect way to get feedback in such a difficult environment'.

However, two respondents became aware of, and started using EVS because of a university/department initiative or incentive as the two comments below indicate:

'Dean of Faculty saw it in operation… and bought some equipment for the Faculty. Advertised through teaching & learning committee';
'Introduced by our Academic Development Centre'.

---

[14] A list of EVS vendors, as provided by Dr. Steve Draper:
http://www.psy.gla.ac.uk/~steve/ilig/tech.html

Two other respondents had also indicated that they started using EVS largely because it was more or less a departmental requirement. The tacit assumption was that any lecturer teaching a particular topic or in a specific department with a history of EVS use was expected to continue the tradition:

'It was a requirement of the module I was teaching. This had been set up by another lecturer two or three years before I started teaching the module';
'It's a standard tool for the Mech. Eng. cohort, so we're expected to use it when teaching them. Colleagues who'd previously taught that cohort also encouraged me to do so'.

In summary, academic staff currently using EVS for mathematics teaching were introduced to the tool in three ways: Through a presentation or demonstration at a conference/seminar; through an institution-wide or departmental policy or initiative of making the systems available to interested staff; and through a department making it a requirement for teaching classes (Table 2.17).

Medium of staff exposure to EVS	Presentation	Institutional Initiative	Course/Departmental Requirement
No. of Respondents	10	4	2

Table 2.17 Data showing the medium through which respondents were introduced to EVS.

2.5.3 PEDAGOGICAL PRINCIPLES FOR USING EVS QUESTIONS

Based on respondent comments to 'What were your guiding principles or goals in choosing/setting EVS questions?', four main themes were identified as the guiding principles for the creation and use of EVS questions in lectures. The first of these was the desire to receive feedback in real time on student performance and grasp of the relevant subject matter. The four comments below, from different respondents, indicate this:

'To gain feedback on students' progress and to highlight common mistakes made by students';
'To be able to quickly assess the level of the students; to provide more informative and instant feedback to students';
'Assess whether the students had understood the basic elements of the material covered between tests';

'To enhance learning and to find out how well particular course items were understood'.

The second main theme was the use of EVS questions to reinforce ideas or topics. This had two expressions: The creation of questions to assess student recall of previously covered material, and assessment of student efficacy in applying newly introduced material. Respondent comments also indicated that the actualisation of this goal often involved the creation of questions that students would find cognitively challenging, as expressed in the excepts below:

'Immediately reinforce each new idea with an EVS question. (ii) Include some more difficult or extended questions to stretch the better students and provide practise solving problems';
'I designed questions to make students think about how they could use the techniques they'd just been taught but also to make sure the techniques were being used appropriately';
'Capturing key principles and framing questions to have several plausible answers';
'Checking what students knew from previous work, wanted students to try questions in lectures to make them aware of where they needed to work';
'Identify content and create questions to revise material from last lecture(s) , lead into introduction of new material'.

The third main theme identified was the use of EVS questions to catalyse engagement, specifically student interaction and participation in class. This is particularly pertinent for those teaching large classes, as the excepts below indicate:

'Student participation in large class environment';
'Getting students to work together and build simple ideas up in a fun way';
'Questions that will prompt discussion between students - so typically not ones that have a numerical answer';
'To improve student lecturer interaction'.

Last, the importance of selecting and creating good distractors was identified as a main principle guiding the use of EVS questions. One respondent commented that EVS questions should have good distractors:

'They must be relevant to the course and have good distractors'.

Another respondent commented that a good distractor must be elimination-proof and not too complicated:

'Good distractor answers. Questions cannot be too complicated otherwise students will be unable to answer. Students should be able to answer questions in a short period of time. Also, the students shouldn't be able to determine the correct answer by a process of elimination from the available selection'.

Some themes that were also mentioned included the need to use EVS questions to highlight common student mistakes and misconceptions, reinforce understanding of concepts, and determine lecture pace. The excerpts below are an example of the expression of these themes:

'Making students aware of weaknesses/common mistakes';
'... Check understanding of concepts as we progress';
'Checking understanding of definitions, e.g. div, grad, curl';
'To better determine the pace of the lecture'.

However, one comment indicated that one of the respondents might not have had a compelling guiding principle for the creation and use of EVS questions:

Very low-fi. I would just write a question on the board and give 4 possible answers.

In summary, the four guiding principles for the creation and usage of EVS questions are:
- Feedback on student understanding of subject matter
- Reinforcement of lecture/curriculum content
- Enhancement of student engagement with learning
- Creation and selection of good distractors

QUESTION TYPES

These principles in turn seemed to have influenced the types of EVS questions used. Based on respondent submissions to the question, 'Could you describe the type of questions you have used with EVS?', four categories of question types were identified. A description of each of four question types or categories, to be presented below, will show that the goals for these questions are to receive feedback, reinforce lecture material or enhance student engagement with learning. The first category comprises questions assessing recall and/or understanding of *previously* introduced material, as evidenced by the following excerpts:

'To determine starting knowledge of student; to determine understanding following explanation of theory in class; to determine if understanding from previous lectures can be recalled';

Questions assessing recall of subject material are a way of receiving feedback on student knowledge.

The second category comprises questions used to assess student efficacy in *applying* recentl*y* introduced material:

This second category of *application-type* questions not only provide feedback on student understanding, but they also help in reinforcing lecture material.

The third category comprises ice breakers which are questions that are typically used to create a relaxed atmosphere in the classroom, in order to facilitate student engagement with learning:

The fourth category comprises questions specifically assessing student understanding of concepts:

This question type is also known as concept tests (Lomen & Robinson, 2004; Mazur, 1997) and may help to reinforce concepts as well as provide feedback on student understanding of the concepts being evaluated.

Another category of questions, comprising questions used to introduce new material (e.g. responder comment: 'introduce new ideas') or ask students to set the agenda (e.g. 'voting on which topics to look at during revision lectures'), was also identified but this category did not occur with the same level of frequency as the main four.

In summary, the four main categories of the types of EVS questions used are:

- Questions assessing recall and understanding of previously introduced material
- Questions assessing student efficacy in applying recently introduced material
- Questions assessing conceptual understanding of subject matter
- Ice breakers

Moreover, these question types seemed predicated on the principles that respondents had earlier indicated guided their creation of EVS questions. For instance, questions assessing recall, and student efficacy in applying recently introduced material are related to the guiding principles of seeking 'feedback on student understanding of subject matter, [and] reinforcement of lecture/curriculum content'.

BENEFIT FOR MATHEMATICAL TOPICS

Further, respondent submissions to a questionnaire item ('Which mathematical topics have you found EVS most beneficial or useful for teaching?') showed that EVS was useful as a teaching aid across various mathematical topics. Its use was not limited to, or shown to be particularly beneficial for a limited range of mathematical topics:

'Any topic with discrete numerical answers (because I was restricted to multi-choice PRS)';
'Generally, techniques / methods rather than longer problem-solving exercises or applications';
'Ones in which the calculation is no more than two or three minutes'
'Understanding the concepts in various topics of Applied Maths, problem solving';
'In general (not topic related): testing knowledge'.

The distinguishing feature of all the comments above is that they are general, descriptive, or pedagogical imperatives for using EVS. The comments describe scenarios where the use of EVS questions would be an effective tool to facilitate general teaching objectives or anticipated learning outcomes. Apart from these pedagogical imperatives, two respondents did state that they had specifically found EVS useful for teaching complex numbers and waves, and forecasting time series:

Perhaps if the respondents had been asked to stipulate the topics they had *not* found EVS useful for, a different picture might have emerged.

USE FOR FORMATIVE ASSESSMENT

Pedagogically, EVS have been mostly used to present MCQs in lectures, as 13 respondents agreed with the statement, [I] 'have used EVS for only multiple choice questions', while another 10 indicated that they 'have used EVS questions for formative assessment purposes only'. Five respondents also indicated that they had used EVS to administer both MCQs and open-ended questions, while another three stated that they had used EVS for both formative and summative assessments (Table 2.18). It therefore appears that the most frequent use of EVS is to present MCQs in lectures for formative assessment purposes. The preponderance of MCQ use is directly related to the availability of handsets that are simple to use but which typically do not allow free text entry. Some of the free text entry systems are simply not very easy or intuitive to use, in addition to being more complicated than the relatively simpler MCQ-focused systems such as TurningPoint ResponseCard RF and InterwriteCricket.

11. For the statements below, please select all that apply:			
Have used EVS for only multiple choice questions (MCQs):		n/a	13
Have used EVS for both MCQs and open-ended questions:		n/a	5
Have used (EVS) questions for formative assessment only:		n/a	10
Have used EVS for both formative and summative assessments:		n/a	3
Have used EVS to formally register attendance:		n/a	2
Other *(please specify)*:		n/a	2

Table 2.18 The most common use of EVS MCQs is for formative assessment .

WHEN QUESTIONS ARE USED

In relation to when EVS questions are used during a lecture, the majority view - in response to the question, 'When during a lecture do you use the questions (e.g. beginning, middle or towards the end of lecture; or questions paced throughout lecture),

56

and why? - seems to be the pacing of EVS questions throughout a lecture session. The three excerpts below are representative of this view:

'... Pace questions throughout the lecture, so that they (I) immediately follow the material that they employ, and (ii) break the lecture into blocks of no more than 20-25 minutes (maximum full-attention span of students!)';
'Mostly paced throughout. It depends to some extent on the class and lecture objectives. For year 1 Calculus I normally start with a few (revision from previous lecture) and then have questions paced throughout. A bit of new material, a few questions to test and draw out new point of interest, more theory/ examples, more questions etc.';
'Questions paced throughout the lecture'.

FOCUSING STUDENT ATTENTION

The first excerpt presented above also highlighted the use of EVS questions as a pedagogical means for splitting a lecture session into distinct (time) blocks for the purpose of maintaining student attention. Submissions from other respondents corroborated this pedagogical affordance of EVS questions in helping to maintain student attention. For example, one respondent stated that S/he used EVS questions in the middle of a lecture session because this provided 'a desirable break' (ostensibly from the tedium of listening and copying notes), while another submitted that s/he used EVS questions towards the end to keep up (student) 'interest':

'Middle. It is a desirable break and it wastes 5 minutes giving out the handsets';
'Towards end, keeping up interest.'

2.5.4 EVALUATING QUESTION EFFECTIVENESS

Instructors who use EVS employ different question types in their classes based on their respective guiding principles. But how do these instructors evaluate whether a question has been effective, or are there criteria that they employ in evaluating the efficacy of EVS questions? In response to the questionnaire item, 'How do you evaluate whether a question has been effective?', respondent submissions indicated that the most frequently used criterion might be 'when student response leads to the identification of problem areas' (Table 2.7). This essentially means that EVS is seen as providing feedback on student strengths and weaknesses.

However, the open comments provided by respondents suggested that the most important criterion for evaluating the effectiveness of a question would depend on the goal for asking the question in the first instance. The excerpts below are representative

of this view (please refer to Table 2.7 to put respondents' comments in the proper perspective):

'It all depends on the type of question. As long as you are respond intelligently then any of the above can be a good outcome. [Option] (1) is only good if you have designed a question with lots of right answers [Option] (2) this tell you to continue without dwelling too long on concepts already understood. [Option] (3) This tells you to slow down and reiterate - but you don't want too many of these! [Option] (4) similar to (3) above. Might need to plan differently for the next lecture. [Option] (5) Depend what sort of unexpected results. Might be a bad questions, but might be a good one to get them talking to each other (and/or you) to adapt';
'It depends on the type of question'.

I had listed the criterion, 'depends on the type of question' in a previous, exploratory study (King & Robinson, 2009c) – and most of the respondents then had selected the 'depends on the goal for asking question' option. I omitted this option from the current study because I conjectured that making a choice from the listed options, which were derived from classroom observations, literature review and informal conversations with EVS users, might help reveal respondent preferences with respect to the options.

Further, four respondents had selected the 'when more students get the answer right' option as the yardstick they would also employ in evaluating question effectiveness. One advantage of this approach, as indicated in the comments of two respondent presented below, is that for easy questions, ostensibly assessing 'basic knowledge', more students getting the answer right would reassure not only the instructor(s) but also the students:

'It depends on the type of question. If I ask a very easy question, I expect most to get it right and therefore spread would be low, but question may be effective in giving students confidence, reassuring me that they do know the easy material, etc';
'Depends on what I am trying to target with the question. Sometimes I need to assess basic knowledge and therefore am looking for the majority of students to get the right answer. sometimes I am testing knowledge from what we have just discussed in the lecture and therefore, need to be able to respond directly to the needs of the students, i.e. good or poor understanding will determine how I then proceed';

Respondents also noted that a question could be considered effective as long as it elicited a response from students, with even a low response rate viewed as positively contributing to learning:

'I'd evaluate a question as INeffective [emphasis respondent's] if none of the students answered it!';
'Practically no response is "useless", so in a sense all questions are effective. If a majority of students respond in some way, the results are always effective either in indicating that they've grasped the material or in helping me target a problem area. If only a minority of students respond, I

regard the question as less effective, but it can still be useful: e.g. it suggests that the pace of the course is leaving people behind (or just, on some occasions, that they're having a dopey day and I shouldn't push the pace!)'.

The 'practically no response is useless comment' suggests that a low student response rate could be as beneficial to an alert instructor as a high response rate. In addition, two other respondents observed that they would generally judge a question effective if it 'produces debates and questions' or creates 'significant discussion between students' in the classroom:

'Mainly when it produces debate and questions (otherwise if I say something that surprises them only a keen three or four come and ask me about it at the end)';
'When the question leads to significant discussion between students about what is the correct answer'.

2.5.5 EFFECT OF TIME ON EVS USE

Based on classroom observations, the number of EVS questions used in a lecture could vary from one to more than 10 questions. However, respondent submissions indicated that the typical number of EVS questions used in mathematics lectures is about six (Table 2.19). If six questions are typically used per lecture and it takes about 90 seconds (based on my classroom observations) for an instructor, with experience using EVS, to present a question and allow students to submit their responses (without accounting for time for feedback, which might be minimal or extensive, depending on student response), then EVS use would require at least nine minutes of lecture time. This means that for a one-hour lecture, which is typically 55 minutes in duration, the instructor has 46 minutes to present instructional material.

How many questions do you typically use per lecture?				
No. of questions used per lecture	1-2	3-4	5-6	>6
Frequency	1	2	6	6

Table 2.19 The number of EVS questions typically used in mathematics lectures.

An instructor using EVS therefore has to make a pedagogical decision – Do I still attempt to cover *all* the required material or curriculum, given the limited period of time available; or do I cover *most* of the material while *focusing* on those aspects which are crucial to student learning (e.g. based on instructor's previous experience, EVS feedback, common student misconceptions in topic, etc), with EVS used as a means to reinforcing and/or assessing student learning as well as providing more targeted instruction? The evidence from respondent submissions suggests that they have adopted coping strategies. This is because *all* the respondents indicated that they had been able to cover the 'required material'. Most (i.e. 12 respondents) stated that they had either 'managed to somehow cover the required material' or 'did not struggle with covering the required material' (Table 2.20). Two factors that might have contributed to the achievement of this goal are experience with using EVS and the use of EVS in two-hour lectures or tutorials, as expressed by the comments below:

'No, I did not struggle with covering the required material: I have quite a bit of experience of using EVS and therefore was able to determine how long each question would take to set, answer and explain to students';
'Yes, but I managed to somehow cover the required material: With year 1 calculus I have 2 one-hour lectures and one two-hour lecture. I only use EVS in the 2 hour lecture. This lecture is much slower paced, but I can speed up in the others to compensate (and then start with revision with the EVS). With year 1 engineers (2 x 1-hour lectures with PRS in both), I find that it does slow me down and occasionally I cancel use of the EVS to maintain speed.'

15. Did you struggle to cover the required (syllabus) material in lectures due to the increased time pressure as a result of EVS use?		
Yes, I could not cover all the required material:	0.0%	0
Yes, but I managed to somehow cover the required material:	31.2%	5
Yes, so I focused on the most essential aspects of the module:	12.5%	2
No, I did not struggle with covering the required material:	43.8%	7
Other *(please specify)*:	12.5%	2

Table 2.20 The relationship between EVS use and instructor's ability to cover the required material in lectures

The second excerpt above indicated that while the respondent 'managed to somehow cover the required material', there were times that s/he had to cancel the use of EVS due to the need 'to maintain [lecture] speed'. Hence time i.e. time available for a lecture and the time it takes to present EVS questions is an important factor to consider when using EVS. However, the issue of time becomes less of a concern with two-hour lectures, if the number of EVS questions used is not more than 10. The lecturer has more time to cover the required material and might even use the timing of the EVS questions as a way of maintaining student interest and attention levels (see later for comments on EVS use for maintaining student attention).

Another time-related factor is the times it takes to create EVS questions. Respondent submissions had indicated that almost all (i.e. 15 respondents) had created their own EVS questions, instead of sourcing the questions from, for example, a designated online or offline database or archive. If the questions were created from scratch, how much time did this require? Respondent submissions showed that eight or half of all respondents had spent 'a great deal of time (i.e. 'significant extra time spent') creating the EVS questions, four had spent a 'moderate amount of time (i.e. 'extra time spent not very significant') creating questions, while four submitted that the time spent was not significant i.e. 'minimal time increase – no significant difference in time spent' (Table 2.15). Hence 75% of all respondents had spent a significant amount of time 'early in the semester' preparing EVS questions.

Respondent submissions to a question on whether there was any difference between the time spent on questions *early* in the semester and *later* in the semester, showed that the amount of time spent creating questions *later* in the semester significantly reduced. Only two respondents still indicated that they spent a great deal of time on question creation, while eight respondents (four more than before) now subscribed to the 'moderate amount of time spent' on question creation category (Table 2.15).

One respondent noted that it was more important to, instead of focusing on the time initially spent creating questions, devote more attention to the ability to fine-tune lecture delivery, often in real time, as a result of EVS feedback. This ability to vary instructional measures based on student feedback is known as contingent teaching (e.g. Draper & Brown, 2004). This is because a bank of suitable EVS questions can be created over a period of time, thereby reducing the time burden for question creation:

'A great deal of time (i.e. significant extra time spent) : If you are going to do this then you have to be willing to react. The time taken to set up the questions therefore doesn't depend on the stage in the

semester. The set of questions prepared for one week should be informed to some extent by the responses from the previous week. However over a period of year you start to build up a bank of questions and can do some selecting/adapting based on similar cohorts in previous years and this significantly reduces the time for creating'.

Another respondent observed that while the initial question creation was time-consuming, there was also a less time-consuming need for a continuous reviewing or 'tweaking' of questions, once they have been created. This is part of the continuous process required in order for questions to better meet student learning needs:

'I prepare most of my material over the summer, i.e. neither earlier nor later in the semester.';'
'Creating /adapting questions took a significant amount of time the first time round (c. 2-3 days to construct questions for the half of the course for which I hadn't inherited them), and a moderate amount in subsequent years. I also spend occasional moderate amounts of time (e.g. 2 hours or so every few weeks) throughout the teaching term, updating or "tweaking" questions'.

However, not everyone experienced time pressures. A respondent commented for instance that there was no difference in the amount of preparation for EVS compared to non-EVS lectures:

'In classes where I use EVS I tend to base the session around the questions I set - the total preparation time for such a session is pretty much in line with the amount of preparation I would put into a session where I was not using EVS'.

Another time-related issue is the logistics of EVS handsets' distribution for use in a class. In the first excerpt above, the respondent observed that giving out the handsets 'wasted five minutes' of lecture time. Another respondent had observed that part of the reason s/he found EVS only 'mildly effective' as a pedagogical tool was due to the time pressures associated with the distribution and organization of the technology:

'None, really. It was mildly effective in testing some very simple mathematics or questions that had limited range of answers. However, the time spent organising it, giving out and getting back the handsets, writing the questions and interfacing them with the EVS software, made all the exercise rather pointless'.

However, this particular issue only (marginally) affects those who have to distribute handsets before a class. Institutions that operate a 'student loan' model generally do not face this difficulty.

2.5.6 CLASS DISCUSSION AND PARTICIPATION

A common pedagogical application of EVS questions is their use in the facilitation of peer discussion (Crouch & Mazur, 2001; Mazur, 1997) or classwide communication (Beatty et al., 2006; Nicol & Boyle, 2003). To gauge the prevalence of this practice in mathematics classrooms, especially given the pedantic nature of many mathematics lectures, respondents were asked to respond to a relevant questionnaire item ('Are students in your class usually encouraged to discuss their answers before or after voting, or engage in peer discussion when EVS is used?').

The feedback showed that respondents are split almost equally into two groups of those who incorporate peer discussion (6 respondents) and those who do not (7 respondents). But the comments from the discussion-incorporating group showed that peer discussion was not always a feature of classroom practice, as its use depended on 'the question' and 'context', among others:

'A mixture, some immediate answers, some discussion';
'Depends on the question and where it sits in the lecture';
'I use a two-stage approach. Stage 1 is individual; stage 2 (if it's required) involves peer discussion before voting again on the same question';
'It depends on the question and in context. In Linear algebra tutorial use YES (before and after) With a large group of level 1 students normally not explicitly encouraged (although a bit of comparing of responses before and after is expected) Sometime I set questions that DO require discussion beforehand - and normally I ask them to discuss with their next door neighbour before responding'.

The group of respondents that did not employ peer discussion cited a number of reasons for this choice. This included the challenge of incorporating this method with a large class (n=270), with one respondent commenting that a class he observed which had incorporated discussion seemed like a 'jamboree' to him; the time required for implementation; and the inability to create the type of questions required to facilitate these discussions:

'Can't do this with a class of 270';
'The colleague who first used the EVS allowed student discussion: I observed one of his lectures and I thought that it was a jamboree where students did what they pleased (I was seated at the back of the lecture theatre and could carefully observe their behaviour). Myself and other colleagues decided to adopt a more formal, exam-like, approach';
'...You have to allow more time for question like this, so I don't use many with big groups';
'Have not been able to produce good enough questions to make discussion worthwhile'.

However, respondents in this group did not appear in principle to be opposed to the idea of incorporating elements of peer discussion into their teaching.

With the increasing exposure and use of EVS, it could be expected that criticisms against its use and proliferation would increase (e.g. Laborde & Strasser, 2010), as research in the field matures. However, one attribute that has seemingly remained constant is the association of student enjoyment and satisfaction with EVS use. One respondent had earlier commented that 'they [i.e. students] like it more than I do'. So it was somewhat not surprising that the overwhelming majority of respondents (n=15) had indicated (in response to the question, 'How would you say that students have responded to the use of EVS?'), that students had shown either 'very positive' or 'positive attitudes towards EVS use'. A respondent observed that student feedback forms showed that EVS was 'the best part of the unit [i.e. course]…' s/he taught in spite of the fact that the EVS use was no longer a novel experience for the students:

'They have shown very positive attitudes towards EVS use: Sometimes I feel the sessions are slowed down too much, but the students response is very positive. In the unit feedback forms student are invited to complete the statement 'the best part of the unit was....' A couple of year back our assessment scheme topped the poll. This is still popular, but now the use of EVS in the Wednesday morning lectures is top of the list. We have used it for 2 hours every week this semester - so it isn't a novelty any more'. They must genuinely find it helpful for learning'.

This respondent also remarked that when students were given the option of attending a lecture with EVS delivery, and one without it, they opted for the EVS option.

One measure of student engagement that has continually been cited as a major advantage of EVS use is increased student participation in class. Classroom observations and student feedback show that even students who are normally indisposed to answering questions in class, respond to EVS question prompts, partly because most responses are sent anonymously. Respondent comments about a related survey item support the notion that increased participation is a major benefit of EVS use. One-half of all (i.e. eight) respondents stated that EVS use 'has significantly increased student participation' based on 'class observation and % of students responding' in class. Further, five respondents commented that EVS use 'has led to a minor increase in student participation, while only three respondents submitted that EVS use 'has had no impact on student participation'.

A related effect is that increased participation together with the feedback provided to questions may encourage students to clarify learning difficulties outside the lecture. As earlier presented, one respondent had commented that the increased

interaction made students to be 'much more likely to ask for further clarification and explanation when they don't understand'. However, there is no evidence that there has been a corresponding increase in student attendance. One respondent noted that although there was 'significant increase in engagement of those attending, [there was] not much difference in the numbers attending lectures'. This observation is consistent with the observations made about student attendance in EVS-enabled lectures at Loughborough University (King & Robinson, 2009b).

2.5.7 COGNITIVE ENGAGEMENT

In many mathematics lectures, students listen to expositions of (new) mathematical content and examples of how this content might be applied, and students take notes based on these expositions. However, students do not typically or frequently solve problems, or be assessed formatively on their understanding of that content within that lecture or subsequent lecture sessions. However, with EVS use there is the possibility of addressing this cognitive vacuum – students sometimes take notes mechanically and are in essence switched off mentally – by providing students with problems related to the content introduced in class. This should facilitate deliberate practice, which could significantly increase cognitive engagement with learning (Bransford et al, 2000).

When respondents were asked about the 'impact (or otherwise) of EVS use on the mental processing or problem solving of in-class material during lectures', many (n=10) stated that they had observed a positive correlation. In the excerpt below, a respondent observed that EVS use had had a 'very significant impact' on student mental processing of problems during lectures. S/he also added that this has implications for learning outside of the walls of the classroom:

'Very significant impact. Before EVS I suspected that a few students worked through problems on the board ahead of me, most watched me solve problems and tried to understand what I did. Now all students have to try problems before they have seen the answer. They need to think how to solve a problem - not just understand my answer - I think this is a very important difference and I think that they will be in a much better position to try other problems out of the lecture setting.'

Another respondent commented that 'all students' are able to 'switch their brains on' during EVS lectures, as opposed to the pre-occupation with note-taking that sometimes occurs in non-EVS lectures:

65

'It encourages ALL [emphasis respondent's] the students to switch their brains on there and then. In non-EVS lectures some students are fully engaged while others sometimes seem to just be taking notes for future use. Some (Maths) students in particular can feel threatened and react adversely (not attending) to lecturers' attempts to encourage participation. The advantage of using EVS is that it is non-threatening. If anonymous there is no reason not to participate'.

Other respondents commented on how increased interactivity, capacity for directing attention, and a focus on problem solving are features of EVS use that have contributed positively to cognitive engagement:

'This has greatly improved. The students now expect the class to be interactive and know that they will be working individually and with others to solve problems during lectures. This means they have become more active rather than passive learners';
'Makes them think more. Makes lectures less mechanical (just note-taking) and wakes them up and gives them something to work on even if they've lost the thread of the lecture';
'System can help students focus a little, allowing them to solve problems more quickly';
'With EVS, I have evidence that some mental processing or problem solving of in- class material occurs during lectures. Without EVS, I'm not sure that any occurs, at least in some classes!'.

However, two respondents were undecided about the impact of EVS use on cognitive engagement, citing insufficient evidence; while four others stated that they had not observed any impact on mental processing of in-class material. One respondent in the latter group commented that the 'EVS system was just a different, more interactive way, of running a multiple choice class test…'. Another respondent had earlier commented that EVS use '…may overemphasise quick-fire questions which are associated with more shallow learning…'. This comment raises the question on whether EVS, because MCQs are the main pedagogical instruments, promotes a shallow approach to learning, even if its use makes students more proficient at problem solving.

However, research evidence (e.g. Draper, 2009; Crouch & Mazur, 2001; Nicol & Boyle, 2004, Beatty et al, 2006) suggests that is possible to create and use MCQs known as concept tests (e.g. Lomen & Robinson, 2004) in a lecture environment to facilitate a deep approach to learning which ultimately culminates in conceptual understanding (e.g. Ramsden, 1992; Entwistle & Ramsden, 1983; Marshall & Case, 2005). Respondent submissions to a related survey item about whether or not EVS use 'reinforces a particular learning style or approach to studying mathematics' seem to support this conclusion. Respondents indicated (Table 2.21) that the learning approach induced would depend on 'the type of questions used' (n=11), 'staff pedagogical styles or practices' (n=11), and 'on the individual student' (n=7). A respondent summed it up best when s/he commented that the learning approach elicited by EVS use would

depend 'on both the lecturer and the student, and the way in which EVS is utilized by both'.

24. Based on your experience of EVS use, would you say the use of EVS reinforces (or otherwise), in students, a particular learning style or approach to studying mathematics?			
EVS use tends to reinforce a surface learning approach to maths:		n/a	1
EVS use tends to reinforce a deep learning approach to maths:		n/a	1
It depends on the type of questions used:		n/a	11
It depends on staff pedagogical styles or practises:		n/a	11
It depends on the individual student:		n/a	7
I do not have sufficient data to verify this:		n/a	5
Other (please specify):		n/a	3
View All Responses - There are too many responses to display on this page and so all the responses to this question are available on a separate page.			

Table 2.21 Relationship between EVS use and impact on student learning approach.

To evaluate whether there was a relationship between EVS use and student 'overall academic performance', respondents were presented with the survey item, 'Would you say you have noticed any impact (or otherwise) of EVS use on student achievement, as measured by grades on formal (summative) assessments'. Their submissions (Table 2.22) indicate that there is currently no evidence that EVS use has contributed to an improvement in student academic scores. Respondents (n=10) stated they either 'do not have sufficient data to verify' any correlation between EVS use and improvement in academic performance or that 'EVS use has little or no effect on overall academic performance' (n=5) [In a similar US survey that I conducted, seven participants (25.1% of respondents) indicated in response to this same item that EVS use had contributed to an improvement in overall academic performance in their classes].

22. Based on your experience of EVS use, would you say you have noticed any impact (or otherwise) of EVS use on student achievement, as measured by grades on formal (summative) assessments?			
EVS use has little or no effect on overall academic performance:		n/a	5
EVS use has contributed to a decline in overall academic performance:		n/a	0
EVS use has led to			

			n/a	1
improvement in overall academic performance:			n/a	1
I do not have sufficient data to verify this:			n/a	10
Other *(please specify)*:			n/a	2

Table 2.22 Correlation between EVS use and improvement or otherwise in student achievement.

2.5.8 FEEDBACK

Along with increased student engagement, the one other main benefit of using EVS cited in literature is the provision of feedback to both students and staff about the level of understanding in a classroom, as illustrated earlier through the conversational framework. So the question may be asked, What types of (student) feedback do instructors receive, and which ones do they value the most? Judging by recurring frequency, the most important types of feedback that instructors have received from students are in consecutive order - this was in response to the survey item, 'Could you describe the kinds of feedback you have *received from* student answers to EVS questions? (see Table 2.11):

'Identification of common student errors or misconceptions' (n=14);
'Identification of components of topics students find difficult' (n=12);
'Student understanding of previous lessons' (n=11);
'Ease/Difficulty level of a question(s)' (n=10).

Similarly based on recurring frequency (i.e. based on respondent submissions to the item, 'Could you describe the kind(s) of feedback you *provide to* students after they have submitted their answers to the EVS questions used in class?'), the most important types of feedback provided by instructors to students are in consecutive order:

'Explanation of why the alternative options provided are incorrect ' (n=14);
'A step-by-step solution of the problem' (n=11);
'Discussion of the distribution [or spread] of students' correct and incorrect answers' (n=11).

It is imperative to point out that it is not feasible for instructors to provide the three different types of feedback highlighted above to every question. Each instructor instead provides the requisite feedback type based on perceived student need (this is often indicated by the response spread). One respondent clarified this when s/he stated that the type of feedback provided:

'...depends on the specific nature of the question, but I would use all of these [i.e. different types of feedback] at different times'.

Another respondent corroborated this when s/he stated that, although s/he preferred giving 'step-by-step solution. s/he would often vary his/her approach based on spread information:

'I don't necessarily provide all these for every question. I always give a step-by-step solution, and I discuss correct and incorrect answers if there's a clear signal in the responses (e.g. many students falling into a particular "trap")'.

It is important to note that the information or intelligence (Russell, 2008) provided by the types of feedback highlighted above, if acted upon, can or should ideally help instructors improve their teaching, while aiding student learning. The limited evidence suggests that instructors are indeed utilizing the feedback received. Most respondents (n=13) stated that they had incorporated feedback from students into their teaching. This incorporation is either in the form of long term revision and updating of course notes or 'on the fly', contingent teaching response in real time within a lecture session, as the excerpts below indicate:

'Each year, when I revise my course material, I bear in mind what I've learned (from EVS as well as other feedback) about the difficulty of various topics, and I try to set questions to challenge common misconceptions. I've altered the pacing and the sequence in which ideas are introduced for similar reasons';
'Only in an "on the fly" sort of way - in that, if lots of students get a question wrong after discussion then I will spend more time going over the ideas behind that question';
'Yes instantly - that's the whole basis on which I use it. Also, at the end of a session (and sometime during it) I jot down thought for future question/adjustments'.

These comments show that at least some EVS-using instructors are actively reflecting on, and improving their teaching practice in the light of feedback received from students.

The importance of feedback was further highlighted when respondents commented about the differences in feedback between EVS and non-EVS lectures – this was in response to the item, 'In general, are there any differences between the feedback provided in a typical mathematics lecture where EVS is used and one in which EVS is not used?'. The majority response (n=12) was that feedback played a far more important role in EVS lectures for a number of reasons. First, the volume of student feedback (including from shy or reticent students) received is much higher than

in traditional lectures:

'Hugely more feedback with EVS. And from different people – e.g. shy people, less keen people, etc.';
'Profound differences! In a typical lecture, IF [emphasis respondent's] a question is asked by the lecturer, typically, the same students will answer each time, and little or no discussion ensues.';
'There's a lot more feedback when EVS is used. (This is not hard given that many students like to sit through a lecture like so many sacks of tatties!)';
'You cannot expect to get feedback from "all" students in a standard lecture environment with 90 students'.

Second, EVS use helps provide an accurate picture of student comprehension of lecture content, and this knowledge of what students actually know or understand may be at odds with instructor presumptions or erroneous impressions about the level of student understanding, which a respondent suggested are often formed by 'talking only to the smart students':

'Without EVS it's easy to be misled about students' talents and impression of the course by only talking to the smart students who ask questions';
'Much more feedback provided. Now have evidence of how many students get question wrong and know how much feedback to give';
'Yes I can be more focused on one particular misconception rather than having to explain misconceptions which might not be present'.

Third, instructors are able to provide more targeted feedback to students, based on insights into student comprehension as indicated by student answer choices:

'In an EVS session, if a majority of students give an incorrect answer, I feel I have to first run through the correct solution AND discuss why students felt the alternatives may have been correct';
'Yes when the EVS is used it allows much more targeted feedback to the students and therefore they find it more relevant and useful';
'Much more feedback provided. Now have evidence of how many students get question wrong and know how much feedback to give';
'Yes I think so because you have something more concrete to feedback on'.

However, one respondent cautioned that it is not advisable to compare the two because his/her teaching objectives are different, depending on whether EVS is used or not. This respondent viewed EVS use as being judicious for 'short questions', in contrast to a lecture where s/he could focus more 'on a single long problem':

'Not easy to compare; two very different styles: In a lecture, I concentrate more on a single long problem while EVS questions tend to be about short questions'.

Similarly, another respondent observed that s/he needed 'normal lectures' to maintain 'the pace of the course', thereby creating the impression that the respondent would want the option of retaining both EVS and non-EVS lectures:

'With the same group in a 'normal' lecture they have to identify themselves what they do and don't understand. BUT I need the 'normal' lectures to keep up the pace of the course'.

Last, a respondent observed that while student participation in instructor-driven EVS lectures had increased, there was no evidence of a corresponding increase in student willingness to participate in lectures without being incentivised by the instructor:

'... I don't see any noticeable effect (positive or negative) on how willing students are to provide other feedback, e.g. by asking questions in the lecture'.

2.5.9 IMPACT ON TEACHING

Respondents were asked to comment on whether they had 'obtained any unexpected results or made any remarkable observations about the impact of EVS' on student learning or their teaching. The feedback on this item indicated that the observed impact is related to either feedback or engagement. In relation to feedback, participants observed that EVS use had provided them with 'a better overall picture' of student understanding, insights into student 'misunderstanding of the most fundamental principles', and what students find hard or easy:

'Have very much enjoyed the feedback presented in the results. Would not wish to return to pre-EVS days';
'One gets a better overall picture (then, say, by the not-by-many handed-in problem sheets)';
'Yes - misunderstanding of the most fundamental principles on occasion';
'I've learnt more about what they find hard and what easy, often with unexpected results'.

The comment from the first excerpt on how the instructor 'would not wish to return to pre-EVS days' is, anecdotally, a sentiment commonly expressed by EVS-using instructors (e.g. Boyle, 2006, p302).

The other 'unexpected result' obtained by some instructors includes the observations that EVS use has 'significantly' increased instructor-student interaction, which has on occasion prompted clarification-seeking proactive learning behaviour in students; and in addition, students find it useful, or it appears popular with them:

'I have significantly better interaction with the students as a result of using EVS, they are much more likely to ask for further clarification and explanation when they don't understand';
'I implemented it in pairs of students, and all of the feedback obtained is very positive about the enforced discussion with peers';
'I was able to ask delicate questions anonymously';
'They like it more than I do!';
'Very popular'.

The two main 'unexpected results' described are therefore insights into student (mis)understanding based on EVS feedback, and increased student engagement with learning. However, some respondents indicated that they had not obtained any unexpected results as a result of using EVS. One commented that s/he had obtained, 'No unexpected results - the fact that students prefer to interact in class did not come as any surprise'. Another suggested that while EVS use may help students and increase engagement with learning, there was no proof as yet that its use was encouraging more than a 'shallow learning' approach to mathematics:

*'Nothing unexpected or remarkable. Many students seem to find it helpful; it does make it easier to feel engaged with the class. One suspicion: it may overemphasise quick-fire questions which are associated with more shallow learning, and perhaps fosters a sense of macho competition which *could* have negative effects. I have no evidence either way on this point, though!'.*

In general, EVS use seems to have had the greatest impact on instructors' teaching practice in the following three areas – based on the recall frequency of respondent submissions to the item, 'In general, in what ways have the use of EVS, including feedback from students, influenced your teaching?':

1. *'Identification of student misconceptions and/or errors' (n=13)*
2. *'Increased lecturer-student interactivity in my lectures' (n=13)*
3. *'Focused more on problem areas' (n=9)*

Identification of student misconceptions, as has been pointed out earlier, is made possible through feedback obtained from student answer choices, which then enables an instructor to subsequently provide targeted feedback to students by, for instance, focusing on 'problem areas'. Thus feedback could be viewed as having the greatest effect on influencing change in teaching approach or instructional practices. Further, EVS use was also cited as influencing, although to a lesser extent, the following areas:

4. *'Enhanced skills for creating and using questions' (n=6)*
5. *'Use of questions helps delineate lecture into discrete segments' (n=5).*

It makes sense to expect that instructor acumen with respect to creating and using EVS questions would be enhanced over time. In addition, EVS questions provide an unobtrusive means for delineating lecture sessions and maintaining student attention.

Further, respondents overwhelmingly signified that EVS could have a major impact on mathematics teaching. Fifteen respondents (i.e. 93.8% of participants) either 'strongly agree' or 'agree' with the statement, 'Based on my experience, EVS is a tool that can significantly enhance the teaching of university mathematics' (Table 2.13) [In a similar US study that I conducted (see Chapter 1.5), 81.5% of respondents 'strongly agree' or 'agree' with the statement outlined above].

Only one respondent 'strongly disagreed' with the statement – and it is important to highlight this because EVS users tend to be enthusiastic although discerning adopters of the technology. This respondent had used EVS only '2-3 times'. Meanwhile, the three other respondents who had used EVS not more than '2-3 times' all 'agreed' with the statement, while four of the 10 respondents who had 'used EVS regularly for 2-3 years' 'strongly agreed' with the statement (Table 2.3).

As one of the instrument validation measures (see section on Reliability, Replicability and Validity), a question (item 18 – see Table 2.12) similar in concept to item 32 (Table 2.13) had earlier been presented to respondents at about the survey midpoint. A cross-tabulation of the responses to the two items shows a consistency in respondent favourable rating of EVS usefulness for mathematics teaching (Table 2.23).

Cross Tabulation

Results are cross tabulated by question "32. Based on my experience, EVS is a tool that can significantly enhance the teaching of university mathematics."

18. Based on your experience, please rate the value of EVS as a tool for the teaching of university mathematics:	Strongly agree	Agree	Undecided	Disagree	Strongly disagree	Totals
Strongly advantageous	4	1	0	0	0	5
Advantageous	0	8	0	0	0	8
Undecided	0	2	0	0	0	2
Disadvantageous	0	0	0	0	0	0
Strongly disadvantageous	0	0	0	0	1	1
Totals	4	11	0	0	1	16

Table 2.23 A correlation of two relevant survey items show that staff consistently rated the usefulness of EVS for mathematics teaching highly.

2.6 OVERCOMING BARRIERS TO USING EVS EFFECTIVELY

From the analysis of the open-ended comments provided by respondents, a number of 'barriers to maximising the use and effectiveness of EVS as a tool for university mathematics teaching' were identified. These barriers could be classified into the following six categories:

- Time
- Cost
- Uncritical promotion of EVS
- Logistics
- Professional development
- Pedagogical limitations

2.6.1 TIME

In informal conversations with academics considering using EVS, time is often cited as the number one concern. This is not unrelated to the pressures of juggling the many demands of life in academia, as the comments below indicate:

'It takes time in a busy curriculum';
'Staff time and pressure on the curriculum'.

Time as a barrier to using EVS could be expressed in three ways. First, there is a learning curve to understanding how to use the technology with confidence:

'Time taken to learn/setup new system'.

Second, question creation, as respondent comments had earlier demonstrated, takes time, at least initially:

'Additional time required firstly to learn how to use the EVS and then prepare questions'.

Third, it takes time to be proficient, confident and effective in using EVS in the long term:

'Time to establish and determine the correct amount of EVS questions to use in a lecture, this comes with experience'.

The issues with time highlighted above would realistically diminish over time –

for instance, learning to use the technology is largely a one-off event. Further, a viable option for overcoming the 'time' barrier is by academics sharing their knowledge with each other. Staff who have developed strategies for maximising lecture time without sacrificing curriculum content could share this know-how with less experienced or flummoxed colleagues. For example, a mathematics instructor[15] who was not polled for this survey, submitted that rather than constricting, EVS use instead 'frees up time':

'I find it difficult now to construct a lecture without using voting questions. My experience is completely different to the usual response of 'I do not have time in my lectures for such systems'. I have found they free up time. By allowing students to discover the maths through questions there is less to say'.

2.6.2 COST

EVS handsets are not cheap (e.g. A Turning Point EVS toolkit consisting of 32 handsets and a receiver retails for £1895). Cost is therefore a barrier to the acquisition of EVS:

'It costs money, and maths departments are poor';
'Expense in purchasing system and enough handsets'.

In essence, most EVS users are able to do so because their respective departments or institutions decided as a matter of policy to make the technology available for use by interested academic staff. It is also possible for instructors considering EVS to request a free trial from EVS vendors. Moreover, there are now less costly alternatives such as tweeting and live polling systems.

2.6.3 UNCRITICAL PROMOTION

There is a tendency for early adopters and enthusiasts of a (new) technology to mainly present the comparative benefits of using the technology. Until recently (e.g. Johnson & Robson, 2008), most of the articles on EVS focused more on the many virtues of using EVS, with scant attention paid to the drawbacks. In identifying and inviting mathematics staff to complete this survey, I found that mathematics departments were often the least enthusiastic about EVS, judging by the uptake rate. Perhaps the

---

[15] Portsmouth University.

lukewarm reception is partly due to the perceived uncritical promotion of EVS. What is clear is that the mathematics community would appreciate a more balanced presentation of EVS merits (and potential demerits):

'Natural cynicism of mathematicians: the more proselytic articles we see claiming that any given innovation will solve everything and have no drawbacks, the less we believe them. (Positive but critical reviews of what the technology does and doesn't do well are the way to persuade us, I think!)'.

A related development is the drive by some institutions to vicariously mandate, instead of encouraging or presenting as a viable option, EVS use. This drive might not only breed resentment in some staff, who are not necessarily convinced about the merits of using EVS (and they have to be able to use the technology effectively), but might also be expected to lead to an ineffective use of the technology, one that is devoid of any meaningful pedagogical rationale.

2.6.4 LOGISTICS

This is a significant barrier to EVS as it is entirely possible for someone who is convinced about EVS merits to be dissuaded from using them due primarily to logistical issues. One issue is the distribution of handsets to students, which a respondent had earlier commented 'wastes 5 minutes' of lecture time. Another is whether a classroom is designed for EVS (i.e. has appropriate equipment for EVS use), especially for those still using infrared handsets. A respondent revealed that s/he had at one point stopped using EVS, due to logistical issues, before resuming their use when the logistical issues were resolved:

'Practical barriers. When I had to carry round the laptop, receivers and handsets and set them up myself I gradually stopped using the equipment. It wasn't feasible if you had to move building or go from one lecture to another. Now I can just book it I use it regularly'.

Another commented on how 'setting up' issues limit the use of EVS:

'The weight of the equipment and time spent setting it up is a major reason why I do not use the equipment frequently'.

There are a number of ways that the logistical barriers could be overcome. First, a loan model, whereby students borrow a handset for the period of instruction requiring EVS is the best way to mitigate the logistical issues. Further, switching from infrared to

radio handsets removes the need to install receivers in a classroom. Since most institutions do not operate a loan model, however, it is essential that a dedicated, on-site support team be available for helps with any EVS-related issues as the following comments indicate:

'If it is set up ready to go then it will be tried, found useful, and incorporated. You ideally need a team of technicians to be responsible for maintaining it so that it can be used without difficultly'.

A related comment is the observation that some institutions do not prioritise or appear to value teaching. As such, efforts expended on improving teaching might not receive due reward or recognition, with this serving as a disincentive to the uptake of an instructional tool such as EVS. As two respondents observed, perceived institutional support for teaching would positively impact on EVS use:

'Institutional recognition of time spent optimising teaching';
'High quality systems, readily available. And a university/department willing to commit the time, effort and money in overhauling its teaching provision'.

2.6.5 PEDAGOGICAL LIMITATIONS

One major pedagogical limitation is the preponderance of MCQs as the assessment tool of choice with EVS – based in part on the limited use of free text entry systems, which afford instructors with more assessment options (Angelo & Cross, 1993). While it is possible to stimulate a deeper approach to learning with questions carefully designed to assess conceptual understanding, these questions require more time, and pedagogical reflection on the teaching and learning goals for creating and using a question. Some instructors have also commented that it is more challenging to create EVS questions for some topics, for example, linear algebra and analysis. The pedagogical limitations therefore include the creation of 'effective' questions, stimulating more than a surface learning approach, and the challenge of using EVS for more advanced mathematical topics:

'Thinking of good questions across the range of the curriculum is a big task - some areas lend themselves to this more than others';
'It's not obvious that it'd be much use for more advanced topics in which longer problems are more common';
'In my case the multi-choice nature of responses and the uni-directional interactivity. I know that more modern systems allow individualised student feedback and this would be a major advantage to my style of teaching';

'Finding/creating good questions'.

To derive maximum benefit from the technology, EVS should ideally be used by staff who have identified how its use could improve their teaching and help their students learn better. A respondent for instance suggested that EVS should only be used 'in contexts where there's an obvious benefit':

'Use it in contexts where there's an obvious benefit, but don't force it into places it doesn't belong. Balance MCQs / short-answer questions with other forms of work (especially written coursework) that test other skills, and keep an eye open for signs that it's biasing things too heavily towards MCQs'.

EVS therefore requires 'careful design of learning and teaching'. In addition, it is good practice for an instructor to have 'clear expectations' about the purpose for using EVS, and to make these expectations clear to students:

'Clear expectations on the part of both the lecturer and the students. Students must be prepared to interact and contribute and understand the benefits they gain. Lecturers must be prepared to respond immediately and directly to the needs of the students'.

Further, there is a need for a reiteration of these expectations when student response appears to be flagging, as it would at times.

2.6.6 PROFESSIONAL DEVELOPMENT

Although most respondents were introduced to EVS through a seminar/conference presentation, respondent submissions and anecdotal evidence indicate a lack of professional development opportunities in the form of seminars for committed (and not just prospective) users, lack of awareness of EVS-specific resources e.g. question databanks, and a supportive community of EVS users, willing to share their expertise formally and informally. Professional development would therefore include staff training in how to effectively implement EVS and provide a [16]platform for mutual sharing of resources and know-how:

---

[16] There is one such community in the UK: Engaging Students Through In-Class Technology (ESTICT) - http://estict.ning.com/.

'Demonstrate to all staff how to effectively implement the use of EVS 2. Convince staff that in the long run it will take up no more time than existing methods 3. Convince staff that they need to be more flexible with respect to delivering course content i.e. may need to be taught at a different rate 4. Convince staff that they need to be proactive with students i.e. react to the answers given during EVS sessions as above plus knowing when to give questions, knowing how much feedback to give, etc';
'Portability of the equipment and training for all staff in its use'.

However, it does not appear that the barriers enumerated above have dampened the enthusiasm of respondents towards continued EVS usage. In response to the question, 'Based on your experience, would you continue to use EVS for future lectures/academic sessions?', 14 respondents (including two of the three respondents who had initially selected the 'other' column') answered in the affirmative (Table 2.24). One respondent indicated s/he had stopped using EVS, while another suggested that s/he would only use EVS if s/he could 'redesign some of the course' [s/he teaches], so as to 'release some time for EVS'. The intention to change some aspects of the context in which EVS was used was shared by six other respondents who had indicated that they would continue EVS use, but 'with modification of the current EVS set-up'. This connotes that there are aspects of the learning environments in which EVS is currently used that would require changes to maximise EVS use. This is not surprising given that different vendors supply EVS systems being used and in addition, the support structures - for the systems as well as the instructors using them - vary widely at the respective institutions.

33. Based on your experience, would you continue to use EVS for future lectures/academic sessions?		
Yes, with no modification of the current EVS set-up:	43.8%	7
Yes, with modification of the current EVS set-up:	31.2%	5
I am indifferent:	0.0%	0
I am not sure:	0.0%	0
No, I have stopped/would definitely stop using EVS:	6.2%	1
Other *(please specify)*:	18.8%	3

- There are too many responses to display on this page and so all the responses to this question are available on a separate page.

Table 2.24 Data showing the commitment of most respondents to continuing to use EVS.

2.7 COMPARISON WITH 2008 STUDY

Although the 2008 study (King & Robsinson, 2009c) was designed for a general

audience, many of the questions used in that survey were used, after relevant modifications, in the current survey. Significantly, respondent submissions to both surveys follow the same consistent pattern. For instance, all eight respondents to the 2008 instrument indicated that they found EVS 'very useful' or 'useful' as 'an aid to teaching'. In addition, the 2008 study indicated that most respondents viewed student attitudes towards EVS use as being positive. All the respondents for that study also indicated that they would continue to use EVS. However, the two mathematics staff who were polled on that study had been unsure about the efficacy of EVS use for mathematics. This was because they had indicated in response to the question, 'Do you think the use of EVS questions is effective for teaching Mathematics in Higher Education?' that they considered EVS 'somewhat' effective for mathematics teaching.

2.8 DISCUSSION AND CONCLUSION

In this chapter I have presented the methodology, results and analysis of data from a survey study designed with a view to answering the research question, What are the views of academic staff using EVS on the impact of the technology on their teaching of university mathematics? I have also illustrated how the twin benefits of EVS use for teaching reported in the literature, enhanced feedback and student engagement with learning may be explained through the conversational framework. Respondent submissions to similar items on the current survey show correspondence with submissions of respondents to the 2008 study. In this section, I will present the conclusions of the study.

First, a review of respondent submissions shows that academic staff were introduced to EVS and started using the system as a result of: Attending a presentation, its availability through a departmental or institutional initiative, or because a department expects its staff to use the tool. It is reasonable to expect that how the staff were introduced to EVS could influence its use. For example, if it were a departmental requirement that EVS be used for teaching mathematics, what effect would this have on staff attitudes towards EVS? On the other hand, staff who are free to choose to use or decide not to use EVS might be expected to display more positive attitudes and probably draw more on pedagogical principles for using EVS. However, the very limited evidence based on submissions from two respondents only (Table 2.25) suggests that making EVS use a departmental requirement might have a negative

impact on the perception of EVS usefulness for mathematics teaching. This is an area for further study.

The four pedagogical principles enumerated by respondents as their rationale for using EVS – to receive feedback on student understanding, reinforce lecture material, enhance student engagement, and create good questions that would challenge students - seem to indicate that they are not using the technology just because it is available, but as a means for achieving specific teaching and learning objectives. Further, EVS is used exclusively for assessment for learning, although the majority of the questions used are MCQs. The average number of questions used per (mathematics) lecture is six, and these questions are structured such that they often serve as a way to maintain student attention during a lecture.

EVS is a tool that can significantly enhance university mathematics teaching	Presentation	Institutional Initiative	Course/Departmental Requirement
Strongly agree	2	2	
Agree	8	2	1
Undecided	0		
Disagree	0		
Strongly disagree	0		1

Table 2.25 A correlation of perception of EVS usefulness with how staff were introduced to EVS.

The EVS questions used are of four varieties: recall, application, and conceptual understanding questions, together with ice breakers. These questions are typically used to present problems requiring not more than two to three minutes, due to lecture time constraints. Moreover, EVS question usage typically does not involve the type of discussion described in Crouch and Mazur (2001), Beatty et al. (2006), and Nicol and Boyle (2004), although half of all respondents include a discursive component in their use of EVS. However, frequent questioning enhances student engagement with learning, as their use 'provide each student with a chance to think about and respond to a question before hearing other students' answers' (Bruff, 2009:199; see also Guthrie &

Carlin, 2004; Frase et al., 1970). However, no impact on student achievement was reported.

A major component of EVS use is the provision of feedback, which might be viewed as consisting of two strands: Feedback that instructors receive from student answer submissions to EVS polling, and the feedback that instructors provide to students. The most important types of feedback that instructors claimed to have received from students are:

- Identification of common student errors or misconceptions;
- Identification of components of topics students find difficult;
- Student understanding of previous lessons;
- Ease/Difficulty level of a question(s).

Similarly, instructors provided the following types of feedback to students:

- Explanation of why the alternative options provided are incorrect;
- A step-by-step solution of the problem;
- Discussion of the distribution [or spread] of students' correct and incorrect answers.

Feedback from students provided instructors with a means of monitoring student comprehension both in real time and over the course of a module. Instructors are also able to use this student feedback to provide more targeted instructional measures. It is important to note that these two forms of feedback, which are an integral part of EVS-enabled lectures, are either largely absent from, or used infrequently in conventional mathematics lectures.

It is also important to note that EVS use is associated with a number of drawbacks. Time – to learn to use the system, create questions, use EVS in lectures and provide feedback, and 'tweak' questions in response to student feedback – is a concern. So also are EVS cost, the perception that EVS is often presented as the next 'big thing' in mathematics instruction, the perceived limited use of MCQs for promoting higher order learning, and the lack of (adequate) professional development opportunities for EVS users. Professional development is sine qua none for effective EVS use because experienced EVS users could, for example, share with their less experienced peers how they have been able to overcome time issues.

In conclusion, EVS is overwhelmingly (i.e. 93.8% of respondents) seen as a 'tool that can significantly enhance the teaching of university mathematics'. Similarly, EVS use is viewed as having the greatest impact on the ability of instructors to identify

student misconceptions, through feedback, which then enables instructors to focus more on the identified problem areas, with the EVS-induced question-and-answer sessions catalysing increased instructor-student interaction.

In the next chapter, I will introduce the research methodology and reliability/validation protocols I employed for the qualitative (interview) studies described in Chapters Four, Five and Six.

CHAPTER THREE

QUALITATIVE RESEARCH METHODOLOGY

3.1 INTRODUCTION

This thesis, as was explained in Chapter One, has two focal points: An investigation of the impact of EVS use on mathematics *teaching* and *learning*. The learning issues were initially investigated or explored through the study described in the first chapter (i.e. King & Robinson, 2009b). To investigate the learning issues more thoroughly, the following *research questions* were adopted:

4. How has the use of EVS impacted (or otherwise) *student engagement* with respect to the learning of mathematics at university (The focus of Chapter Four)?

5. What is the *student's approach to learning mathematics* (Chapter Five); and how has the use of EVS questions influenced (or otherwise) *student approach to learning mathematics* (Chapter Six)?

To answer these research questions, I designed a qualitative research study (Bryman, 2008, p369), consisting of one-on-one interviews with 10 students, whereby I investigated the impact of EVS use on mathematics learning, with the students on the MAB104 (engineering mathematics) module as my study sample. Further, the interview data is supplemented by documentary evidence from the intended learning outcomes' specification for the module, the module assessment structure, and application of a multi-theoretical framework i.e. theories of learning in the interpretation of data. In this chapter, I will present the *methodology*, including the *analytical techniques* and *reliability/validity* measures I adopted for the interview study. The study results will subsequently be presented in Chapters Four, Five and Six.

3.2 INTERVIEW METHODOLOGY

Different ways of viewing the world shape different ways of researching the world.
(Crotty, 1998, p66)
Ontological assumptions give rise to epistemological assumptions; these, in turn, give rise to issues of instrumentation and data collection.   (Cohen, Manion & Morrison, 2007, p5)

The research design for this qualitative research study is *inductive* in nature, as a main focus of the study is 'drawing generalisable inferences out of observations' (Bryman, 2008, p11). The results of the study are thus 'grounded in the data generated by the research act' (Cohen, Manion & Morrison, 2007, p22). Further, the data analysis and results are presented from an *interpretivist* (epistemological) framework. This framework is concerned with 'laying bare how members of a social group interpret the world around them' (Bryman, 2008, p17). In this case, the students interviewed represent the 'group', while the 'world' consists of EVS use for learning mathematics. In addition, the study assumes a *constructionist* approach (e.g. see Chapter 5.2) because this research study is focused on presenting the interpretations of respondents about learning mathematics with EVS. Therefore the research accounts presented in this and the next three chapters are constructions rather than definitive conceptualisations of respondent learning experiences with EVS (Bryman, 2008, p19).

The ontological and epistemological positions above were adopted because they provided the best 'fitness-for-purpose' (Cohen, Manion & Morrison, 2007:354, p501) with respect to the adoption of the appropriate 'instrumentation and data collection methods' (Cohen, Manion & Morrison, 2007, p5) for the realisation of the research objectives of this study. This was because I had selected the conduct of one-on-one interviews with students as the most viable means of conducting a finer-grained investigation of EVS impact on mathematics learning rather than, for example, the use of surveys or focus groups. The main benefit of the interview as a research instrument in this regard is that I could use it both to validate the results I got from the exploratory (survey) study described earlier, and to 'go deeper into the motivations of respondents and their reasons for responding as they do' (Cohen, Manion & Morrison, 2007, p351). The interview would also provide me with rich, contextualised data that I could draw *generalisable inferences*, which represent *valid constructions* about the impact of EVS use on student learning of mathematics.

Further, I adopted a semi-structured interview approach, and this will be discussed later. Although the study data consists mainly of interviewee transcripts, these are supplemented where appropriate with observations (Bryman, 2008, p257) of EVS use in the classroom and documentary (Bryman, 2008, p515) evidence (e.g. module specification, interviewee results, etc).

3.2.1 SAMPLE

The target sample for the study was second-year Automotive (auto) and Aeronautical (aero) Engineering students who were taught the mathematics module, Engineering Mathematics 3 (i.e. MAB104) in the 2008/2009 academic year, with a total class size of about 150 students. Four female and six male students from auto and aero volunteered for the interviews. Auto and aero departments were selected for a number of reasons. First, the main instructor[17] I am working with in investigating the impact of EVS on mathematics teaching and learning (I have worked with other EVS instructors) teaches this particular group of students. Further, I had administered a survey to the previous year's cohort and as such, there was an element of continuity in researching a class taught by the same instructor in two successive years.

Moreover, this cohort of second-year engineering students had been introduced to the use of EVS in their first year mathematics modules, taught by two other instructors, although only one used EVS. It could thus be expected that their views on EVS use would be more mature or at least be immune to an extent from the novelty effect of EVS use, than students who had just been introduced to EVS. Therefore, my sampling approach could be construed as *purposive sampling* (Bryman, 2008, p458):

Most writers on sampling in qualitative research based on interviews recommend that purposive sampling is conducted. Such sampling is essentially strategic and entails an attempt to establish a good correspondence between research questions and sampling.

It should be noted that students in aero or auto are considered above average in mathematical proficiency, having obtained grade A or B in A-level mathematics as a requirement for admission into the engineering programme.

---

[17] This 'main instructor' is my supervisor.

3.2.2 RECRUITMENT

I was invited by the instructor to come along to two tutorials so I could the use the opportunity to invite students to volunteer for the interviews - my target was to have as many students as possible volunteer for the interviews. Before the tutorials, I had requested the timetables for the two classes (i.e. aero and auto), and identified the times that students were most likely to be available for the interviews. So I went into the class, I had a table in Word, including dates and time slots, into which potential volunteers could input their names and availability for the interviews. However, only six students signed up when I visited the tutorials for recruitment purposes. To get more students to sign up, the instructor invited me to a larger, combined class of the aero and auto students and more students signed up during this event. In addition, the instructor helped send an email message about the interviews to all the students taking the mathematics module, so they all had an equal opportunity to participate.

In the end, 19 students indicated their willingness to volunteer for the interviews. However, I was only able to interview 10 students. Some of the students who had initially indicated their willingness to participate either withdrew from the study or later failed to show up on the day. The scheduling was also problematic. The interviews were scheduled towards the end of term, which was when students had a heavy workload consisting of assignments, essays and various projects. So some students were understandably unable to participate, although they had earlier indicated their availability for the interviews. Moreover, I could not schedule the interviews for another period because I wanted to interview the students only after they had had nearly a full term of exposure to EVS use on the engineering mathematics module.

After the tenth interview I decided, in consultation with my supervisor, that I had established a sufficient sample size for the study. This was because by the time I conducted the fifth, sixth and seventh interviews, I noticed that the same themes were coming up, and even some of the unscheduled comments from interviewees broached similar issues. Therefore, I decided to stop interviewing students after the tenth interview, as I had reached the level of 'data saturation', the level at which it is recommended for an interviewer to bring to a close the interview process (e.g. Guest et al. 2006, p65 as quoted in Bryman, 2008, p462; Boyce & Neal, 2006).

3.2.3 METHOD

I employed a semi-structured interview (Bryman, 2008, p438; Cohen, Manion & Morrison, 2007, p352) approach to interview the 10 volunteer students. This approach observes a protocol whereby 'a series of questions, statements or items are presented and the respondents are asked to answer, respond to or comment on them in a way they think best. There is a clear structure, sequence and focus, but the format is open-ended, enabling respondents to reply in their own terms'. So the structure is adequate to ensure consistency of question content and presentation across respondents, yet flexible to accommodate unanticipated (respondent) comments or observations. The interviews therefore consisted of a set of well-structured questions that students could respond to flexibly.

As a result of the previous survey (explorative) study on EVS impact on student learning (together with the survey on impact of EVS use on teaching, study visits, feedback from conference presentations as well as from members of the MEC research panel), I had acquired substantial knowledge on the ways that EVS use may influence learning. However, there were still many gaps in that knowledge. I therefore adopted the semi-structured interview (Bryman, 2008, p438; Cohen, Manion & Morrison, 2007, p352) approach as the most effective means of addressing these 'gaps', in agreement with the recommendation that: 'The structured interview is useful when researchers are aware of what they do not know and therefore are in a position to frame questions that will supply the knowledge required' (Cohen, Manion & Morrison, 2007, p354).

3.2.4 THE INTERVIEW PROTOCOL

I conducted the individual interviews with the 10 students who volunteered for the study at the MEC between January/February 2009, and 60 minutes was allocated for each interview. Apart from having to sign the Consent Form and the Compensation Form (see Appendix E) acknowledging that the student had received £10, students were presented with five sets of questions, based on the *interview protocol* or *schedule*, I adopted for the study. Apart from the first set of questions to which students responded in writing, the other sets were the questions I asked during the interviews, and these required oral responses from students.

The *first set of questions* that students had to complete was contained in the Pre-Interview Questionnaire, which consisted of six items (see Table 3.1 for the questions). The purpose of these six questions was to assess student perceptions of their

proficiency and attitude to studying mathematics (Q1 and Q2); student learning intentions or goals and the strategies they adopted to achieve the goals (Q4 and Q5); and investigating the general impact of EVS use on the module (Q3 and Q6). It should be noted that the time students spent completing the Consent and Compensation forms as well as the Pre-Interview Questionnaire did not count towards the 60-minute time allocated for the interviews.

1. How proficient would you say you are in mathematics? Please circle one.   Very good   Good   Average   Poor   Very poor
2. Before obtaining admission to Loughborough, Would you say you were looking forward to studying mathematics at university level? Please elaborate on your answer.
3. In what <u>way(s)</u> has the use of voting systems in MAB104 hindered or helped your learning/revision of Calculus?
4. What is your goal(s) for the MAB104 module e.g. Get a pass grade; Get a 100% score; Get a real understanding of course content; etc
5. What do you think you need to know or do to achieve your goal(s)?
6. Would you say the way or the rate you are learning in the MAB104 module is similar or different to the way or the rate you are learning in your other modules? Why is this so (Please explain)?

Table 3.1 The Pre-Interview Questionnaire containing the first set of questions presented to interviewees.

The *second set of questions* was basically to review the submissions of respondents on the pre-interview questionnaire i.e. the first set of questions – by asking them to clarify their submissions to each of the items in the questionnaire. I decided to do this because, in a previous study with Sports Technology (see Chapter One) students where I adopted a protocol similar to the one I adopted here, I did not review the answers that students provided in the questionnaire section. It was only later, while I was reviewing the submissions, that I discovered that some of them did not make sense, and would have benefited from a follow-up question and answer session, simply to clarify the responses.

The *third set of questions* was basically on the use of EVS in class. Some of the questions (e.g. benefits and disadvantages of using EVS) had been used before in my survey-based studies. However, some questions e.g. Q4 and Q5 were new (see Table 3.2 below).

Third set of questions
1. What are the disadvantages/problems (if any) of using handsets in lectures?
2. What are the benefits (if any) of using handsets in lectures?
3. Were there times you did not vote in class?
4. Does EVS help you think more about a question or topic? How?
5. How do you feel when an EVS question (i.e. because it's too hard or easy) puts you on the spot?
6. Any other comments?

Table 3.2 The third set of questions presented to interviewees.

The *fourth set of questions* (Table 3.3) dealt with a range of issues including student strategies for overcoming challenging mathematics problems, the role of EVS in relation to feedback, and the effects of 'multiple select' (when more than one option is correct) and 'response range' (the range of the answers selected by students, as shown on a classroom display in the form of a bar chart, immediately after a voting session).

Fourth set of questions
1. Questions to identify study habits and learning strategies e.g. what do you do after you get a question wrong; or how do you prepare for assessments?
2. Feedback questions: What are your views about the feedback you get? Does it help you identify clearly where you went wrong, show you how you can get it right the next time? Enough time for feedback?
3. Questions to identify multiple select and response range effects.

Table 3.3 The fourth set of questions presented to interviewees.

The *fifth set of questions* consisted wholly of EVS questions that had been previously used in class for the engineering mathematics module under investigation. The questions were based on the topics that had been covered in class, including Multiple Integration, Fourier Series and Vector Calculus. The main rationale for the inclusion of the questions was to assess whether and/or how the use of EVS questions had influenced the learning of mathematics on the module.

The interview questions were selected after discussions with the module instructor. The instructor had also explained to me why she developed the questions, and the learning objectives she was hoping to achieve by presenting students with the questions discussed (see Appendix C for the interview protocol).

THE FIFTH SET OF QUESTIONS: In all, the fifth set of questions consisted of 18 EVS questions (see Appendix G), although only 14 of these were used with every interviewee. The rest of the questions were included as time-fillers, used only when time permitted. However, it should be noted that although 14 questions were used, in reality, only six distinctive questions were used (see Figures 3.1 – 3.7). This was because each question e.g. Q2 was often asked or reproduced in two or three different formats, but with each format or question testing the same mathematical skills.

Moreover the six questions, representing different topics, were the ones identified by the instructor as being the most significant – the questions which students had either struggled with in class, or the ones for which the instructor wanted to see the kind of impact the questions had had on students. Interviewees were required to answer these questions during the interviews. The six questions, numbered Q1 to Q6 are presented below - together with the answers and response range, in exactly the same format in which they would have been presented to students in class, and which I replicated in the interviews – this means that the questions were first presented, with the answers displayed only after students had submitted their responses:
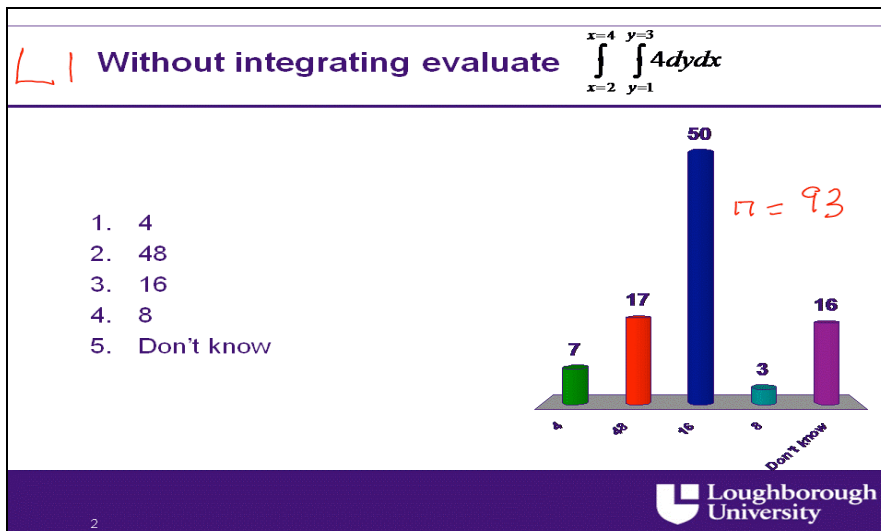
Figure 3.1 Q1 An EVS question on double integration[18].
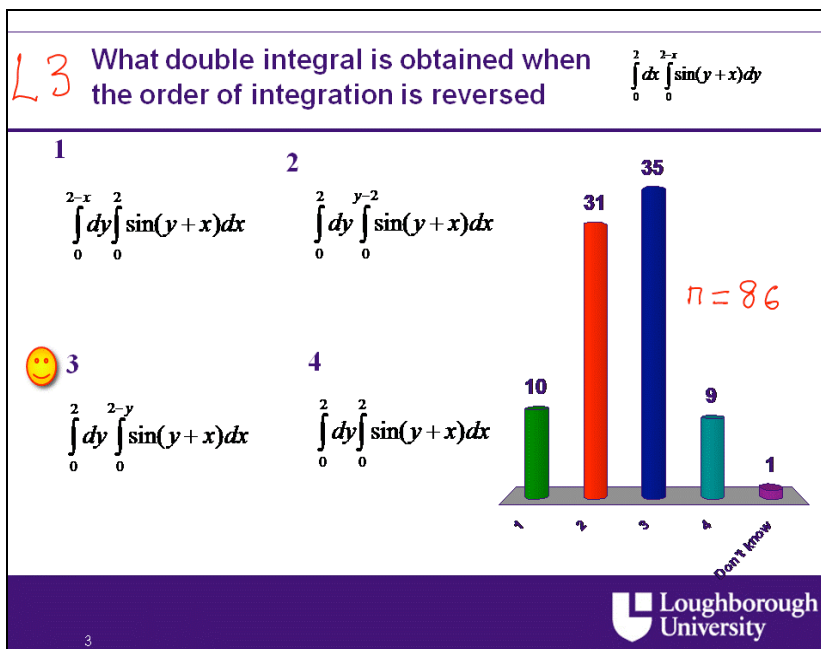
Figure 3.2 Q2 An EVS question on the reversal of the order of integration.

---

[18] The 'L1' inscription denotes that the question was presented in the first lecture for the module. Similarly, 'L3' denotes 3rd lecture, 'L11' – 11th lecture, etc.
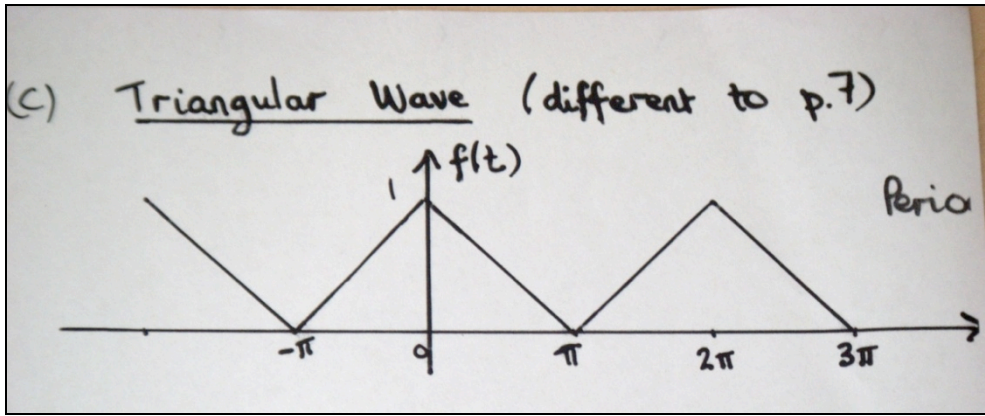
Figure 3.3 The triangular wave on which Q3 (shown in Figure 3.4) is based[19].
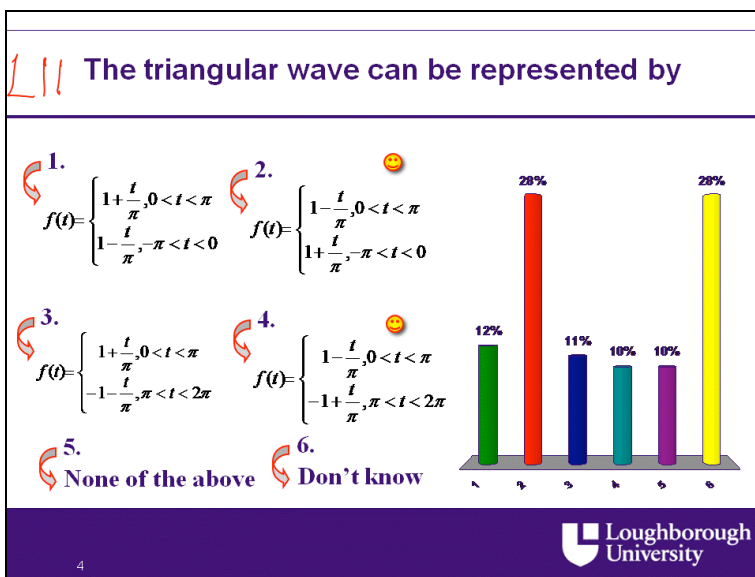
Figure 3.4 Q3 An EVS question on a triangular wave[20].

---

[19] Note the phrase, 'different to 7' is redundant i.e. not part of the picture.

[20] A sketch of the wave is provided in Figure 3.3.
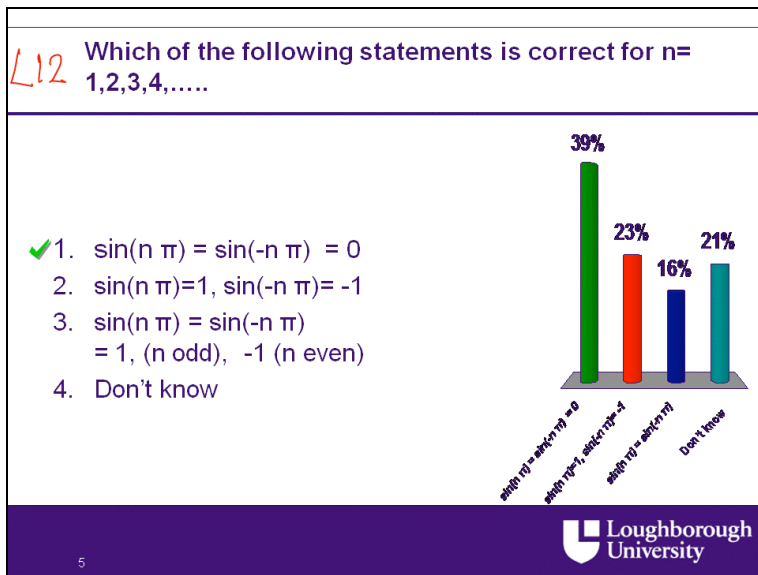
Figure 3.5 Q4 An EVS question on sine calculation, knowledge of which is required for Fourier Series.
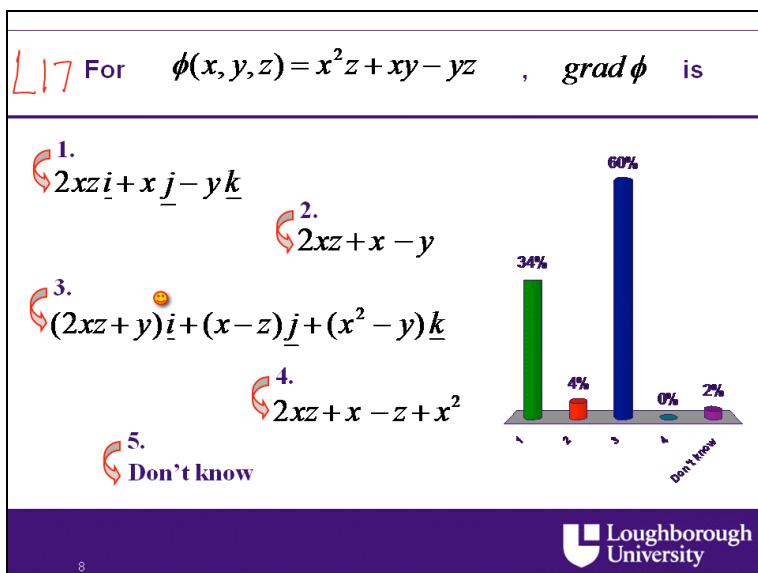
Figure 3.6 Q5 An EVS question on Vector Calculus.
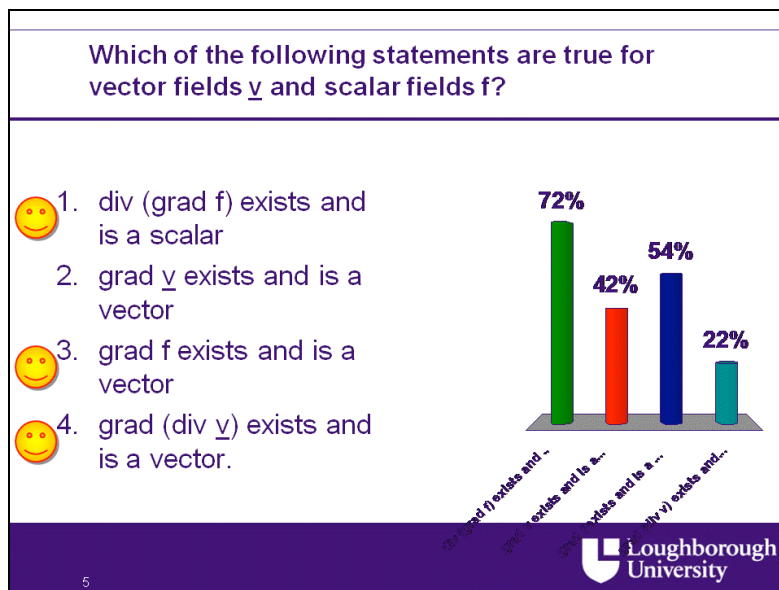
Figure 3.7 Q6 An EVS question on Vector Calculus.

Further, one reason why I asked interviewees to answer the six questions presented above was because I wanted to gain an insight into interviewee (and by extension, student) problem solving skills. This enabled me to evaluate the impact or otherwise of the use of EVS questions on student approach to learning (see Chapter Six).

3.2.5 TRANSCRIPTIONS

The interviews were conducted between January 12th, 2009 (the date of the first interview), and February 6th, 2009 (the date of the last i.e. tenth interview). All the interviews were recorded on audio (I also attempted to record two of the interviews with Flip Video (see Appendix J for a brief report), which then had to be transcribed.

Initially, I attempted to transcribe the audiotapes myself, but I struggled considerably. First, I type very slowly and cannot touch type. Second, I discovered that I could not analyse the data while I was transcribing. In essence, I was switched off mentally whenever I was transcribing. So I could not really take advantage of the main benefit that had been cited in support of the argument for researchers (graduate students especially) transcribing their own interview data – that is, the act of transcribing gets a student acquainted with the data. Due to these constraints, the audiotapes were transcribed professionally.

To ensure quality, samples of the same audiotaped interview were sent to four transcribers. I then selected the transcriber who produced the best transcription quality. The transcripts from the audiotapes consist of 108,457 words (401 pages) of interview material, apart from data from the pre-interview questionnaire.

3.2.6 ETHICS

The study, as well as subsequent ones, was conducted in accordance with the principles set out in the Loughborough University Ethical Guidance form. In essence, I sought student permission, before audio and/or video recording the interviews. This permission was obtained orally and by requiring students to sign the Consent Form (see Appendix E). I also informed all the interviewees that they had the right to walk away from the interviews at any time (although I always followed that up by joking that I hoped that they would not take the option).

I have adopted the use of pseudonyms (K1 – K10) to refer to individual interviewees. I have also employed gender-neutral descriptions of interviewee responses, specifically in Chapter Five where I focus on individual interviewees, to further protect their privacy. In addition, only the research panel overseeing my study and I have access to respondent data. Moreover, I have been careful to reassure respondents and to indicate to them that my characterisations of their approaches to learning are merely characterisations; and that these are not meant to be prescriptive or definitive, or a gauge of their ability or motivation for learning (see respondent validation in Section 3.4.1).

Further, the students who volunteered for the study were paid £10, as re-imbursement for the time spent in the interviews. They also had to sign a form (see Appendix E) that they had collected the said amount.

3.3 DATA ANALYSIS

I subscribe to the notion that analysis starts, not with, but before data collection. I think a study should be approached or designed, as much as is feasible, in a manner that facilitates or is congruent with how the data would be analysed. This was why I adopted a semi-structured interview approach to data collection for this study, with an interview protocol consisting of five sets of questions, as described in the preceding section. Due

to this structured approach to the interviews, I knew the type or subset of answers that each category or set of questions would generate. Analysing the transcripts was thus made easier in the sense that I had a sense of what each section of the transcript was about, based on the structure of the interview protocol which I more or less followed.

However, as my approach was semi-structured, I was still able to take into consideration student comments that did not strictly fall into my pre-defined categories. This was because it was relatively easy to identify the submissions or responses that did not fit the pre-defined categories. Often during the interviews, I would follow up such threads with additional questions to interviewees, and it was easy reading through the transcripts, to identify such additional material that did not necessarily fall within the pre-defined categories, as indicated by the five sets of questions used during the interviews.

Further, in analysing the data, I employed thematic analysis (Bryman, 2008, p554). This facilitated the identification and grouping of relevant themes and sub-themes, with the organisation, structure and presentation of the themes dictated by my research questions on a macro scale, and the interview questions (as explained earlier) on a micro level. Using questions to guide the analysis 'is a very useful way of organising data, as it draws together all the relevant data for the exact issue of concern to the researcher, and preserves the coherence of the material' (Cohen, Manion & Morrison, 2007, p468). In this section, I will explain in detail the procedures I adopted in using the research and interview questions to guide the sequencing and presentation of themes through the thematic analysis approach.
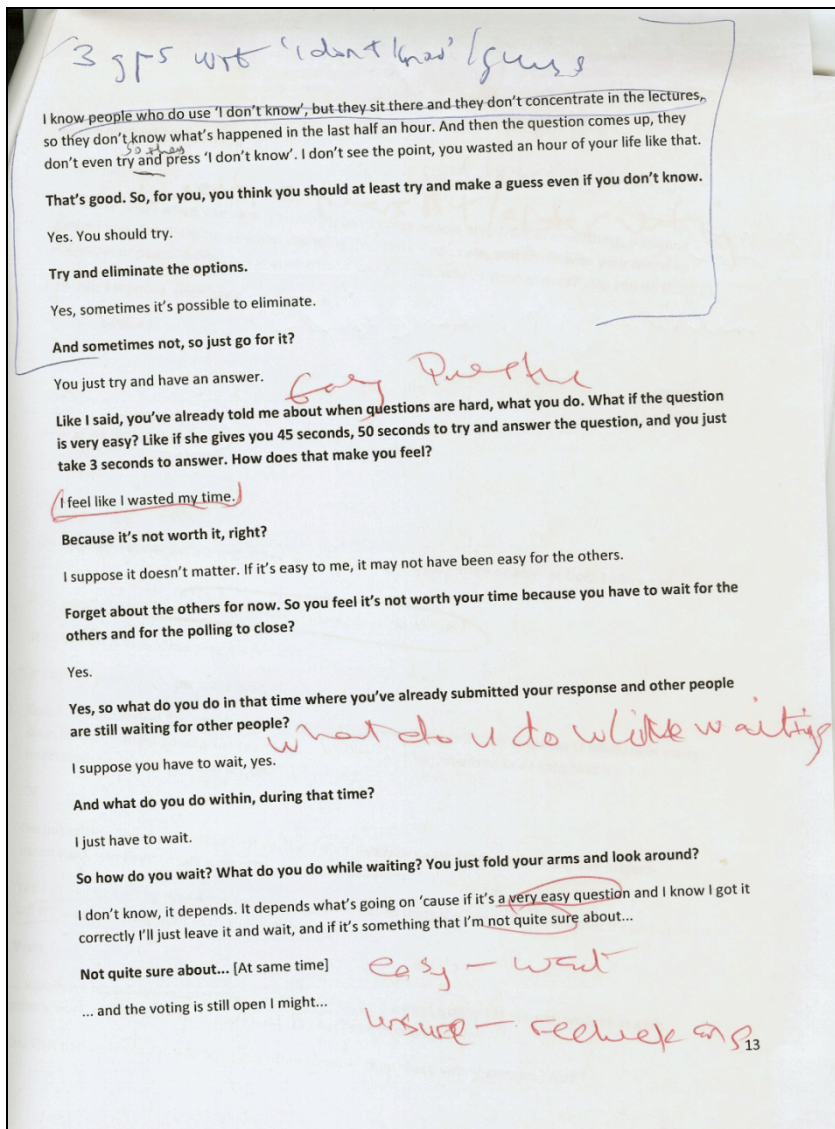
Figure 3.8 A sample of how I annotated or coded interviewee transcripts to identify relevant categories.

3.3.1 INDIVIDUAL INTERVIEWEE TRANSCRIPT ANNOTATION

The *first stage in the analysis of interviewee transcripts* was the annotation or coding of the transcripts for each of the ten interviewees. As I have earlier stated, each transcript consisted roughly of five sections, based on the five sets of questions, which were presented to interviewees in the same consecutive order. So I read through each of the transcripts and annotated each by hand.

For example (see Figure 3.8), reading through a page of an interview transcript belonging to the fifth student I interviewed (whom I have code-named K5), I annotated each sentence block based on what the conversation was about, and how it related to

aspects of my research questions or objectives. So in Figure 3.8, the page featured as an extract includes the following annotations: '3 groups with respect to 'I don't know'/guess' (i.e. I could see that the students I had interviewed up to that point seemed to fall into three categories with respect to how they used the 'I don't know' option, which was a regular feature in the EVS questions used in class (please see Chapter Six for a thorough discussion about the role of guesswork in EVS use). I also used square brackets to link sentence block(s) of interest to corresponding annotations.

- 3 Groups with respect to 'I don't know'
1. Those that guess instead of selecting 'I don't know';
2. Those who click 'I don't know
3. Those who attempt every question cf K5
4. Couldn't be bothered or was not paying attention
5. Those with negative connotations of I don't know
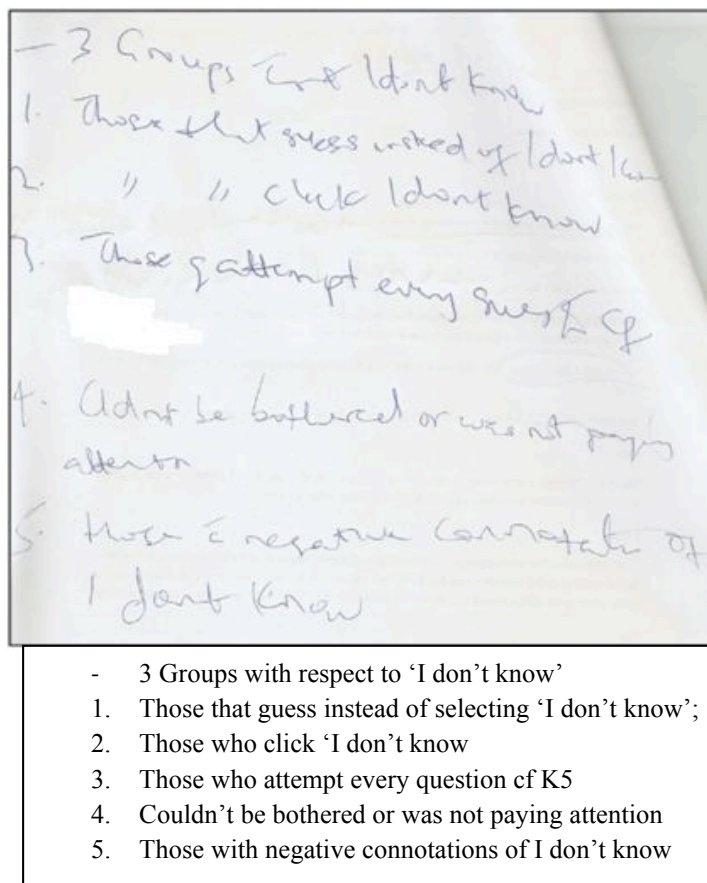
Figure 3.9 An example of how I clarified the annotations I made[21].

When I printed the transcripts, I deliberately printed them only on one side, so I could use the blank or flip side to write comments on the annotations as necessary. For example, on the flip page (Figure 3.9) of the exhibit earlier shown (i.e. in Figure 3.8), I expounded on what I meant by the annotation, '3 groups with respect to 'I don't

---

[21] N.B. The text box below the figure is simply to present a legible representation of the text presented in the figure above it.

know'/guess' (as shown in Figure 3.8). This was a technique I regularly employed. Further, on the same page (Figure 3.8), I had annotations such as 'Easy Questions', 'What do you do while waiting', 'Easy – wait', and 'Unsure – recheck answer'. These annotations all had to do with the theme, student behaviour, in this case, K5, during EVS question and answer sessions, especially when the student found the EVS question easy to answer.
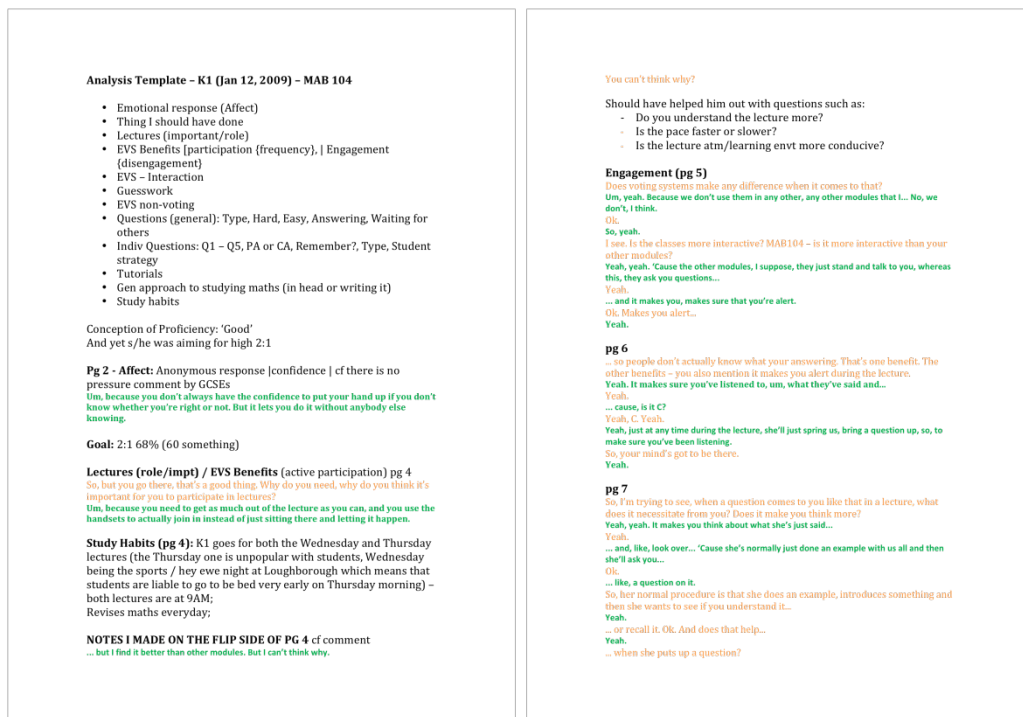
Figure 3.10 The analysis template for the interviewee, K1.

In the *first stage of analysis* therefore, I went through each interviewee transcript and annotated the transcripts as necessary, following my predefined categories (as indicated by the five sets of questions), and guided by my research objectives. But this coding was not linear as I often went back and amended, deleted or included new annotations in the transcripts earlier annotated, based on information encountered in the later transcripts.

3.3.2 COMPUTER-BASED WORD PROCESSING

In the *second stage of analysis*, I read though each of the transcripts again, and updated and streamlined the annotations into what I referred to as *macro themes*, by grouping similar annotations or comments together. For instance, the annotations 'Easy

Questions', 'What do you do while waiting', 'Easy – wait', and 'Unsure – recheck answer' (from Figure 3.8) all came under one macro theme, 'Hard|Easy Questions'. I then created what I refer to as an analysis template i.e. a separate Word document for each interviewee transcript consisting of macro themes based on the revised annotations on the hand-annotated transcripts. Ten such analysis templates or Word documents were created, one for each interviewee (see Figure 3.10). Some of the *macro themes* are: Study habits (annotations or students comments about the study strategies they adopted in and out of class), Engagement (also labelled affect, and which I later delineated into emotional, behavioural and cognitive engagement), guesswork, EVS disadvantages, non-voting, evidence for procedural or conceptual approach, general approach to studying mathematics, individual questions i.e. Q1 – Q6, et cetera. This *thematic analysis* approach (Bryman, 2008, p554; Cohen, Manion & Morrison, 2007, pp467-468) thus facilitated the identification of relevant themes and sub-themes.

Each analysis template consisted of the macro themes in the (chronological) order in which I encountered them, as I annotated each transcript from the first to the last page. In addition, I referenced each macro theme and annotations falling under it to the actual pages in the transcripts where the annotations may be found, to facilitate easier checking and/or making any necessary upgrades and amendments. I also included in the analysis templates the 'flip side' comments I had made on the blank side of the manually marked transcripts. Therefore, the analysis templates at this stage consisted wholly of macro themes and associated annotations in chronological order.

3.3.3 ANALYSIS – STUDENT ENGAGEMENT

Based on the research questions, I had three main objectives for the analysis of the data collected for the studies described in the next three chapters: To evaluate, from interviewee comments, the impact of EVS use on student engagement; To characterise the student approach to learning mathematics, and; To evaluate the impact of the use of EVS questions on student approach to learning mathematics.

To analyse the impact of EVS use on student engagement, I made further changes to the analysis template. Essentially, I changed the chronological order of the analysis templates into a theme-based one. To make this conversion, I went through each of the ten individual interviewee templates and identified all the macro themes that were associated with engagement. These themes were: Affect or Emotional Engagement (with the following sub-themes anonymity, confidence, deflation, elation,

emotional challenge, perception of learning environment, novelty, etc), Participation, Interaction (teacher- student, peer discussion, technical interactivity), Deliberate Practice or Cognitive Engagement, Behavioural Engagement, and EVS Disadvantages.

Affect: Anonymity, confidence, deflation, elation, emotional challenge

Introduction
Quote on emotional engagement supported by

- How mood affects (K10)
- K4's table on emotional component of doing maths
- Panic cf K5

Body

- Attitude towards usefulness
- Perception of learning environment
- Spread: absolute and relative performance
- Relative Performance: reassurance (I'm not stupid + tracking wrt class cf competition in engineering class
- Easy | Hard questions – elation | deflation
- Healthy competition
- Anonymity (two attributes): increased participation + unmasks emotional uncertainties – ridicule, embarrassment
- Pace | boredom
- Novelty
- Formative purpose
- Interconnectedness

1

K1

Questionnaire
'Allows you to answer questions to see if you are at the same level as the rest of the group [i.e. anonymity + relative performance]

And this question says 'in what ways has the use of voting systems in MAB104 hindered or helped your learning of additional calculus?' And you said it helps you to answer anonymously, so nobody needs to know what you…

Yeah.

… how you answered. Why is that important?

Um, because you don't always have the confidence to put your hand up if you don't know whether you're right or not. But it lets you do it without anybody else knowing.

… if you think about the classes you've had, what would you say are the disadvantages for using those? Any side, disadvantages or problems that you've noticed?

Um, not really, no. No, I just think they add to the lecture more than…

Yeah.

… more than anything.

They add… Say that again?

That they add to the lecture, that –

Yeah, I did, I did vote on this. But I can't remember what I put.

No. What I'm trying to get at is why do you remember? Is there, can you tell me? Do you remember enough to know that 'this is why I remember'?

I think it's because before, we talked about contours…

Yeah.

… and what they were. I think she just went through this question more. I think that's… And that made me think of, of that.

2

Figure 3.11 A snapshot of the template for all affect-related themes presented in chronological order.

In the *third stage of analysis* and specifically for evaluating EVS impact on student engagement, I created analysis templates for each of the engagement-related macro themes identified above, together with the associated sub-themes. For instance, I pulled all the annotations and comments relating to Affect or Emotional Engagement from the analysis template of the first student I interviewed (whom I coded K1), and put these into a new word document, which I called the Affect template.

I proceeded to follow the same procedure for the remaining nine analysis templates by pulling all Affect-related themes from these templates and putting them into the Affect template in chronological order.

So in the end, I had an Affect template that consisted of all the Affect-related macro and sub-themes from all the interview transcripts. However, the engagement-related templates at this stage for Affect, Interaction, Deliberate Practice, etc were in chronological rather than coherent order – the Affect sub-themes were not grouped

102

together in a meaningful or coherent manner, but were presented in the order they occurred in the individual analysis templates for interviewees (Figure 3.11).
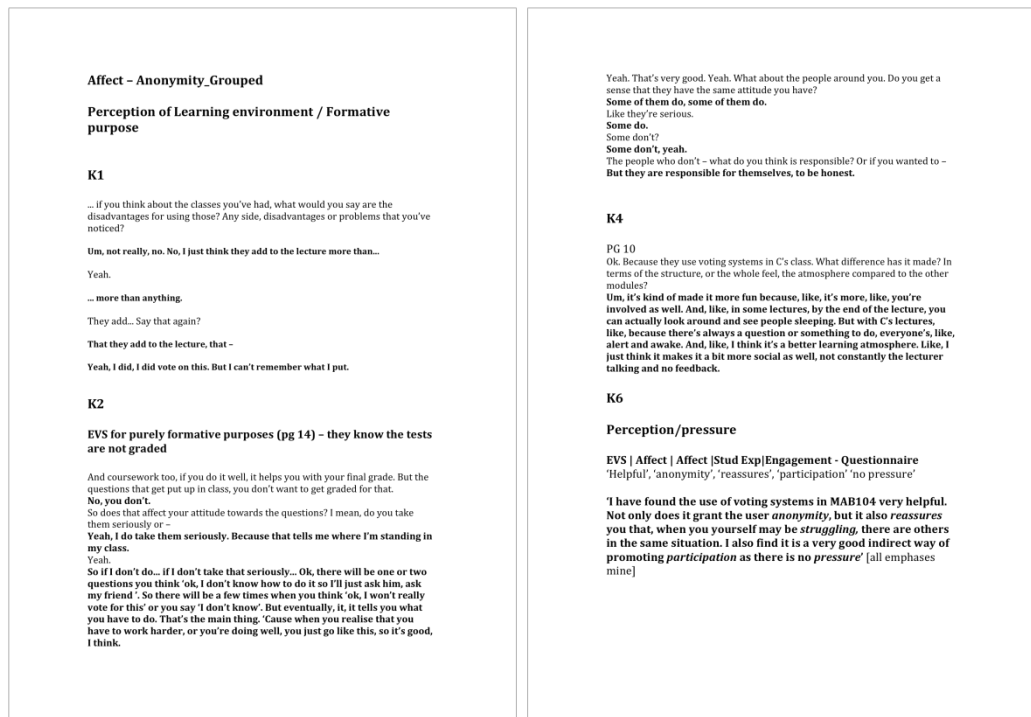
Figure 3.12 A snapshot of the template for all affect-related themes in logical rather than chronological order.

Therefore, in the *fourth stage of analysis*, I sought to give all the engagement-related templates a coherent structure by grouping together all related sub-themes. For example, under the template for Affect or Emotional Engagement, I brought together all the comments and annotations relating to the sub-theme, 'perception of learning environment' in one section (see Figure 3.12). Similarly, the other sections were devoted to bringing together, in discrete sections, annotations and comments under the respective affect sub-themes, anonymity, novelty, etc. In essence, I changed the unit of analysis from being interviewee-dependent (i.e. presenting engagement-related themes based on individual interviewee descriptions, as reflected in the respective analysis templates) to theme–dependent (i.e. presenting each engagement-related sub-themes, such as affect and interaction *across* individual interview descriptions).

3.3.4 CONTINUOUS REVIEW AND ITERATION

The final product that I used in analysing the transcript data for assessing the impact of EVS on student engagement are the engagement-related sub-theme templates described above. However, I did not just discard the documents I earlier used – the original, manually marked transcripts, the ten analysis templates for each of the interviewees, and the ungrouped engagement –related sub-theme templates. Again and again, I referred to and reread these initial documents, especially the annotated interviewee transcripts, in analysing the data on engagement and making inferences and reaching conclusions or presenting conjectures about patterns identified in the data. My aim in doing this was to ensure sure that my analysis was not isolated from the context in which interviewees originally provided their views on the substantive issues discussed during the interviews.

3.3.5 ANALYSIS – STUDENT APPROACH TO LEARNING

The analysis template, the product of the second stage of analysis, did not undergo a third and fourth stages of development with respect to its use in assessing the impact of EVS use on student approach to learning. This was largely because my analysis of data on this aspect was going to be interviewee-dependent i.e. 'the total responses of a single participant are presented, and then the analysis moves on to the next individual…[as] this preserves the coherence and integrity of the individual's response and enables a whole picture of that person to be presented' (Cohen, Manion & Morrison, 2007, p467). This approach was therefore adopted to unearth or expose the particular learning approach(es) favoured by the respective interviewees. However, a discussion of the interconnectedness of the themes across interviewees is presented at the end of Chapter Five.

The sections of the analysis templates that were instrumental in exposing any inherent approaches to learning included Q4 and Q5 on the pre-interview questionnaire. Student responses to these two questions highlighted their *intentions* or goals for learning, and the associated *strategies* for accomplishing these objectives. Further, I was able gain more insight into the rationale for the answers provided by interviewees to Q4 and Q5 through the second set of interview questions described earlier in this

chapter. The rationale for the adoption of this *intention/strategy* interface (Case & Marshall, 2004) will be presented in Chapter Five.

In addition, some of the other comments that illuminated interviewees' approaches to learning were those I coded under the themes 'study habits', 'evidence for PA' i.e. evidence for procedural or surface approach, and 'evidence for CA' i.e. evidence for conceptual approach. Further, interviewees' approaches to solving the mathematics questions that were presented to them during the course of the interviews often provided an insight into how the respective interviewees approached mathematics learning and/or problem solving.

Moreover, two other interpretation devices were used in analysing the interview data with respect to student approach to learning. First, the course structure for the engineering mathematics module, which the students profiled/interviewed are enrolled on, will be presented in Chapter Six to show how this structure may or may not have influenced student approach to learning. In addition to the course structure, that chapter will also include a presentation on how the use of EVS questions in a mode to support formative assessment, a mode I have termed formative teaching, influences student approach to learning.

The second interpretation device used in analysing the data on student approach is educational learning or cognitive theories. Apart from the Case and Marshall (2004) study, from which I adopted the intention/strategy interface for analysing data, I would be employing goal theory and the three worlds of mathematics (Tall, 2008) in analysing and characterising student (interviewee) approaches to learning.

A summary of the analysis structure is presented in Table 3.4.

Analysis Structure Followed – General	
1. Research and interview question-guided thematic analysis approach (Cohen, Manion & Morrison, 2007:468; Bryman, 2008:554)	
2. Data collection intentionally structured to meet research objectives via adoption of semi-structured interview approach and design of interview protocol	
3. Exhaustive reading and manual annotation of individual interviewee transcripts	
4. Transference of annotations, flip side comments into a coherent, word-based document labelled Analysis Template in a thematic layout	
Analysis Structure Followed – Specific	
Engagement	**Approach to Learning**
5. Conversion of Analysis Template into Ungrouped Engagement-related sub-theme templates e.g. Affect template	**5.** Specific sections of the individual interviewee Analysis Templates e.g. study habits, evidence for PA, etc
6. Conversion of each ungrouped template to grouped or coherent Engagement-related sub-theme template	**6.** Adoption of Intention/Strategy interface from Case and Marshall (2004)
	7. Exposition of the influence of course structure and/or use of EVS questions for formative teaching on student learning approach
	8. Goal theory
	9. Three worlds of mathematics

Table 3.4 A simplified description of the analysis structure adapted for this study.

3.3.6 ATLAS TI AND COMPUTER-BASED WORD PROCESSING

The data analysis of the interview transcripts was done via computer-based Word processing. However, a computer-aided qualitative data analysis software (CAQDAS) package such as Atlas T.I. or Nvivo, could have been used. I decided against the use of

a CAQDAS package, after extensively researching the Atlas TI package, for a number of reasons.

First, my guiding principle for using technology is that technology should be seen as *servant*, and not *master* (Olive et al, 2009, p156). So I do not start with which technology should be used. Rather, I decide what my objectives are, and then decide which technological tool may provide the most suitable or adaptable solution.

Second, I adopted the computer-based analytical technique I used based on the principle of *specificity*. This means that the choice of technology used should depend on its suitability for meeting stated objectives i.e. it should satisfy the *fit-for-purpose* criterion (Cohen, Manion & Morrison, 2007, p501). The analytical technique I used was specifically developed in response to the largely structured format of the interview protocol, based on the fact that I knew which sections of the interview protocol addressed which concepts. So the analytical technique was a specific solution to address specific objectives. In contrast, CAQDAS packages were largely designed to help researchers analyse relatively unstructured data, based on the grounded theory paradigm (Coffey et al., 1994; Kelle, 2004). For example, Kelle (2004) claims that 'there may be problems [with using CAQDAS software for qualitative data analysis] where assumptions behind the software may not accord with those of the researchers or correspond to the researchers' purposes, and that the software does not enable the range and richness of analytic techniques that are associated with qualitative research …[and] that it may drive the analysis rather than vice versa' (p283, as quoted in Cohen, Manion & Morrison, 2007, p489).

Third, the technique I used makes *transparent,* to interested third parties, all the procedures and processes I undertook in analysing the interview data. This is because all related documents are readily available for verification, and interested third parties do not need to have access to my codes and CAQDAS account to access all these documents. Thus the technique I used satisfies the principle of *transparency*. In contrast, interested third parties have limited access to documents within a CAQDAS package that is operationalised by an individual researcher involved in non-collaborative research.

Fourth, as my analytical protocol was not platform-dependent (e.g. a CAQDAS package may only be used on the workstations on which it has been installed), I was able to *access* and conduct data analysis at any time. This was important during the

analytical and writing up process, as I frequently used several workstations in the MEC, and at home. I could not have done this with a CAQDAS package. Thus the technique I used satisfies the principle of anytime *access*.

Fifth, in Stanley and Temple (1995), the authors present the approach I adopted i.e. Word-based computer processing as a viable option for conducting qualitative data analysis (see also Kelle, 2004; LeCompte & Preissle, 1993). Further, I sent relevant sections of my findings and an overview of the analytical protocol I adopted to members of the MEC research panel, and the students I interviewed, as well as the academics, including David Tall (Tall, 2008), Jennifer Case and Delia Marshall (Case & Marshall, 2004), whose theoretical frameworks underpin some sections of the interview protocol. These steps were all taken to ensure *standardisation* and the *integrity* of the analytical technique I adopted.

3.4 RELIABILITY AND VALIDITY

The validity of an instrument or research approach such as an interview (as employed in this study) is usually described as 'whether an item or instrument measures or describes what it is supposed to measure or describe' (Bell, 2005, 117). For the purposes of this study, I am construing validity as the 'design of research to provide credible conclusions; whether the evidence which the research offers can bear the weight of the interpretation that is put on it' (Sapsford & Jupp, 1996), as quoted in Bell, 2005. Further, Bell (2005) describes reliability as:

The extent to which a test or procedure [e.g. interviews] produces similar results under constant conditions on all occasions. A clock which runs ten minutes slow on some days and fast on other days is unreliable. A factual question which may produce one type of answer on one occasion but a different answer on another is equally unreliable'.   *(p117)*

The relationship between validity and reliability is that the conclusions reached from a study cannot be said to be valid if the reliability of the instrument is in question. However, if the instrument or data collection/analysis procedure is shown to be reliable, this does not necessarily mean that the procedure is valid as well. Both reliability and validity must be established for the conclusions or inferences/derivations of a study to be considered valid.

To measure reliability and validity, I adopted Lincoln and Guba's (1985) trustworthiness criteria, as described in Bryman (2008, p377), because these criteria

were specifically developed for the measurement of reliability and validity in a qualitative research context. The four criteria are:

1. Credibility – which parallels internal validity;
2. Transferability – which parallels external validity;
3. Dependability – which parallels reliability;
4. Confirmability – which parallels objectivity.

3.4.1 CREDIBILITY

Lincoln and Guba (1985) explained that '…a major trustworthiness criterion is *credibility* in the eyes of the information sources [e.g. study sample], for without such credibility the findings and conclusions [of study] as a whole cannot be found credible by the consumer of the inquiry report' (p213). A recommended mechanism for ensuring credibility is *respondent* or *member validation*, which Bryman (2008, p377) defined as a 'process whereby a researcher provides the people on whom he or she has conducted research with an account of his or her findings. The aim of this exercise is to seek corroboration or otherwise of the account that the researcher has arrived at'.

To ensure credibility of this research account via the mechanism of respondent validation, I emailed all ten students who participated in the interview study, the results of which are presented in the next three chapters, with a summary of my conclusions on their approaches to learning. This summary included not only a synopsis of my characterisation of the interviewees' preferred approach to learning the mathematics module as expressed through their interview submissions, but it also contained a brief description of the technical terminologies I used in arriving at my characterisations and conclusions about their learning approaches (see Appendix D for a sample of the letter I sent to all ten interviewees). In the email, I also sought to reassure students that my characterisations are not definitive of their approach to learning (see Ethics - Section 3.2.6). I did not receive any post-study comments from the students interviewed.

3.4.2 TRANSFERABILITY

Transferability may be described as the 'degree to which findings [from a study] can be generalised across social settings' (Bryman, 2008, p376) or making 'generalisations from one context to another' (Lincoln & Guba, 1985, p123). In qualitative research, transferability may be established by providing 'thick descriptions' (Geertz, 1973) – that is, the 'provision of sufficient information about the context in which an inquiry is

carried out so that anyone else interested in transferability has a base of information appropriate to the judgment' (Lincoln & Guba, 1985, p124).

The need to establish transferability is one of the main reasons why I have provided detailed accounts (see Chapter Six) of the course context and structure, intended learning outcomes, assessment structure, and instructor pedagogical practices for the engineering mathematics (MAB104) module that the students who were interviewed for this study were enrolled on. I have also provided a description of how EVS-based mathematics questions are used to support formative assessment (an approach I refer to as formative teaching), and how this may have influenced student approach to learning.

3.4.3 DEPENDABILITY AND CONFIRMABILITY

Dependability refers to the degree to which the findings of a study are reliable. Confirmability is concerned with the establishment of researcher objectivity in the conduct of the research project. The researcher should be able to show that 'he or she has not overtly allowed personal values or theoretical inclinations manifestly to sway the conduct of the research and the findings derived from it' (Bryman, 2008, p379). To ensure dependability and confirmability, Lincoln and Guba (1985, p317) recommend the adoption of an 'audit' approach, which Bryman (2008) describes thus:

This entails ensuring that complete records are kept of all phases of the research process – problem formation, selection of research participants, fieldwork notes, interview transcripts, data analysis decisions, and so on in an accessible manner. Peers would then act as auditors, possibly during the course of the research and certainly at the end to establish how far proper procedures are being and have been followed. This would include assessing the degree to which theoretical inferences can be justified. *(p378)*

Lincoln and Guba (1985) distinguish two types of audits for dependability and confirmability. The *dependability audit* is concerned with *process* – ensuring that the steps, methodologies, processes are sound, justified and appropriate for the study undertaken. The *confirmability audit* is an attestation that the research *product* i.e. 'the data, findings, interpretations and recommendations is 'supported by data and is internally coherent so that the "bottom line" may be accepted' (p318).

To ensure dependability and confirmability, I have adopted the audit approach by 'keeping complete records of all phases of the research process'. These records include the spreadsheet/table I used in recruiting interviewees, the interview protocol

consisting of all the materials and questions I used during the interviews, audiotapes of the interviews in virtual formats, transcripts of all interviews, documents detailing the thematic analysis techniques I used in making theoretical inferences and the documents (i.e. analysis templates) I produced as a result, sample of the emails I sent for respondent validation purposes, and draft chapters of my thesis.

Further, as part of the internal process for evaluating the progress of PhD students, I had to submit copies of some of the records highlighted above to three persons – my supervisor as well as two members of the academic team supervising PhD student research at the MEC. The feedback I received from these academics was helpful in conducting my own audit, thus helping to establish the dependability and confirmability of both the process and product of the research respectively.

3.4.4 OTHER VALIDITY MEASURES

One measure I have adopted, in addition to the four (trustworthiness) criteria outlined above, is *face validity*, which might be established by asking 'those with experience or expertise in a field…to act as judges to determine whether on the face of it, the measure seems to reflect the concept concerned' (Bryman, 2008, p152). To ensure face validity for the interviews, I submitted the materials used in the interviews to my supervisor who read them through and provided me with feedback and corrections. We also sat together to discuss and select the mathematics questions I presented to students during the interviews.

Second, I had earlier used or *piloted* an interview schedule similar to the interview protocol I used in this study in another study, which was based on two focus group sessions with first-year Sports Technology Students at Loughborough University. It was as a result of a review of the submissions of the Sports Technology students to the pre-interview questionnaire that I identified the need to introduce a second set of questions during the interviews for this study (with engineering students), in order to clarify interviewee submissions on the pre-interview questionnaire.

Third, another approach to facilitate greater validity is to *minimise bias*, which may be due to a number of interviewer, interviewee and interview context factors (Cohen, Manion & Morrison, 2007, p150). One of these factors is the notion of *acquiescence* (Cohen, Manion & Morrison, 2007, p151), which is the observation that interviewees often feel obliged to agree with, or support the direction in which a research study appears to be heading. In this study for example, students knew that a

main objective was to investigate the impact on their mathematics learning of the EVS systems that they had used in lectures. It could therefore be expected that some of the students would feel obliged to supply responses that would confirm or highlight only the positive utility of EVS. The students might also have wanted to please the module instructor by volunteering only favourable responses.

To negate or limit the influence of the *acquiescence factor*, I reassured interviewees that all their contributions would be treated with confidentiality, and that even the instructor would appreciate genuine feedback about the perceived benefits and drawbacks of EVS use. Further, I often directly required students to talk not just about the benefits of using EVS, but also about its disadvantages. The excerpts below (in which I encouraged interviewees K7 and K3 to enumerate EVS disadvantages) are examples of how I overcame the acquiescence barrier – interviewee responses are in bold:

Ok. When I asked you about voting systems the other time, I, everything you said was beneficial. So it's good. And that's great. But can you cast your mind back, I mean, in class, any other experience in lectures when you were there. Try to remember – any time like you felt 'oh, this aspect or that aspect – it's detrimental, a disadvantage or downside to the use of voting systems'.

K7: The only thing I can think of is if, towards the end of a subject...

Yeah.

K7: ... we've had to rush, because when we're asked questions, of course, it takes time out of our lecture schedule.

Yeah.

K7: And if we don't, if a lower majority of people get it, um, right, than what was expected, we'll then go over it, which then, of course, adds on a bit more time.

Yeah.

K7: In a couple of hours we haven't done voting systems because we haven't had time. We've had one, I can't remember what topic it is, but we only had a couple of lectures so we didn't have voting systems to get it done. So the only thing I can really think of is the time it actually takes.

………
……………………………………………

With respect to other students. And, identify reasons for weakness, ideal to identify ... [Becomes unclear] Has there ever been any ways that it's hindered your progress? I mean, you know, these are all very good – it's beneficial. But it can also be detrimental in a sense.

K3: Um. I'd say at times... Well, I haven't experienced this myself but I know a couple people who've said... whereas... The question is put up on the board and they're only worked through afterwards, whereas it's very much – there's the question, there's the four answers. And I find that a lot of people – you can get drawn into guessing. Whereas, obviously, if you're told 'work this out', even if you don't get the right answer, you're actually still going through the process of this.

Although leading questions are as a rule discouraged, on occasion as the excerpt above indicates, I used leading questions in a positive way (e.g. Kvale, 1996, p158) as quoted in Cohen, Manion & Morrison, 2007, p151). But on refection, I think that the most effective tool I used in combating acquiescence and generally making interviewees answer questions as objectively as possible was making them feel comfortable during the interview process. When they came into the interview room, which was well lit and roomy, I welcomed them warmly and sought the requisite permissions before proceeding with the interview. I also told them that the interview was not a test of their mathematics ability, and whenever I said this, I could usually see the relief on their faces. Here is an extract from my interview with K9 about this issue (again, interviewee words are in bold):

Thank you very much for coming, K9[22]. And, um, thank you for filling this questionnaire. The setup for this whole session is going to last mostly in the next 55, 60 minutes. Is the... I'm going to go through your responses to this questionnaire, just to see what you wrote there and what you were thinking. And secondly I'm going to ask you about questions from voting systems, those kind of, the answers you're using in [[23]]class to respond to questions.

Ok.

And then I'm going to put up some mathematical questions based on what you did in class and ask for your response to that. Now, I need to state from the beginning that I'm not testing your mathematical knowledge or ability. What I'm interested in is how voting systems have impacted or hindered your learning of mathematics, especially on the MAB104 module. That's what I'm interested in. And I'll also be exploring your learning approach to mathematics, so it's what you, how you approach mathematics learning and what you do. So that's what I'm basically interested in now. I know you guys are good, in a way – the Aeronautic people so you're very good. So there's not a problem with that. Are you Aero-Auto?

---

[22] This is one of the pseudonyms ascribed to interviewees to protect their privacy.

[23] Name of instructor removed.

To minimise bias which may arise due to the *'misperceptions on the part of the interviewer of what the respondent is saying'* (Cohen, Manion & Morrison, 2007, p150), I occasionally asked interviewees to repeat their statements, just to confirm that I understood what they said, and also so that they could have an opportunity to correct any misunderstandings. Here is an excerpt from the interview with K1 demonstrating this (interviewee words are in bold):

Before you do that, just let me ask you, generally, when you see a question in maths like that, what's your approach to solve it? Do you have to sketch to solve it? Or sometimes you can just look at the question and work it out in your head.

I think when it's, well, the diagram's simple like that, I think you can do it...

Yeah.

... off your head. But I don't normally use sketching methods; I've always done algebraic methods, to be honest. I've never...

Um, say that again? I didn't get it. You were saying if it's, if it's a very simple question, you can work it out in your head.

Yeah.

But if it's something you need to think about, then you, it's better for you to write it down?

Yeah, rather than do graphs or anything like that. I'd rather do it with numbers and...

Yeah. It makes sense.

3.5 CONCLUSION

In this chapter, I have presented the methodological, analytical and validation procedures that I employed for the qualitative research-based interview studies that I conducted with a group of students. Under methodology, I presented the research design and epistemological framework, sample characteristics and recruitment, and the semi-structured interview format that I adopted. I also presented the five sets of questions that I presented to interviewees as part of the interview protocol that I followed. Further, I explained how the data was transcribed and the ethical regulations I observed in the conduct of the study.

Under data analysis, I explained how I employed thematic analysis, guided by my research and interview questions, as the framework for data analysis through five stages. I also presented examples and data extracts of how I derived themes and sub-themes from the transcripts, and how these were subsequently used to analyse and interpret data, with respect to student engagement and approach to learning, which were my research objectives for the study.

In addition, I have presented comprehensive information about the procedures I adopted to ensure reliability and validity. These procedures included the establishment of credibility, transferability, dependability and confirmability of the study within a qualitative research context. I also explained how I adopted other measures such as instrument piloting, face validity, bias minimisation and mitigation of acquiescence to minimise invalidity and further strengthen the reliability and validity of the study.

Although I have attempted to be as objective as possible in the conduct of the study, I cannot say with certainty that all sources of bias have been minimised or eliminated, or that I did not use any inappropriate leading questions during the interviews. However, I have conducted the research in good faith and I accept full responsibility for any part of the research that might not be above reproach.

This chapter provides the methodological background for the interview study, the results of which are presented in Chapters Four, Five and Six. The presentations are in three chapters because each chapter provides insights into the research questions adopted for the interview study as follows:

- How has the use of EVS impacted (or otherwise) *student engagement* with respect to the learning of mathematics at university (Chapter Four)?
- What is the *student's approach to learning mathematics* (Chapter Five)
- How has the use of EVS questions influenced (or otherwise) *student approach to learning mathematics* (Chapter Six)?

In the next chapter therefore, I will present evidence on how EVS has impacted student engagement, based on analysis of the interview data.

CHAPTER FOUR

THE IMPACT OF THE USE OF ELECTRONIC VOTING SYSTEMS ON STUDENT ENGAGEMENT

4.1 INTRODUCTION

In the previous chapter, I introduced the methodology, analytical procedures and validation measures that I adopted for the interview studies I conducted with 10 second-year students on an engineering mathematics module (see Chapter 3.2.1 for sample characteristics). In this chapter, I will present evidence on how EVS use has influenced student engagement with respect to mathematics learning. The findings that will be presented in this chapter are based on analysis of data with respect to the research question, How has the use of EVS impacted (or otherwise) *student engagement* with respect to the learning of mathematics at university?

The chapter begins with background information on the role and types of student engagement in learning. This is then followed by a presentation of how EVS use has influenced the three dimensions of student engagement earlier presented. The next sections will focus on a brief enumeration of the disadvantages of EVS use and a discussion/concluding section about the interconnectedness of the three different strands of student engagement.

4.1.1 BACKGROUND

Research indicates that the use of EVS could significantly increase student engagement (e.g. Caldwell, 2007, Simpson & Oliver, 2007; Fies & Marshall, 2007). In fact, in the initial studies I conducted on EVS use I concluded, based on the evidence from research literature on EVS implementations at other institutions, that 'The single most important benefit of EVS use…is its capacity to enhance, catalyse or increase student engagement during lectures' (King & Robinson, 2009b).

Student engagement is particularly critical in mathematics because it is a learning field that students often struggle with, and one which frequently generates

feelings of apathy, alienation and inadequacy in students. This is one reason why there has been a proliferation of mathematics support centres in universities across the UK – to provide extra resources for students struggling with the mathematical components of their university courses. Moreover, research strongly indicates that engagement has a highly positive correlation (Table 4.1) with increase in student achievement and attendance or retention rates (e.g. Helme & Clarke, 2001; Fredricks et al., 2002; Blumenfeld & Meece, 1988; Marks, 2000; Connell et al, 1995; Boyle, 2001; King & Robinson, 2009b). Research in mathematics education may therefore be 'strengthened if researchers integrate affective issues into studies of cognition and instruction' (McLeod, 1992, p575).

However, student engagement, specifically in relation to EVS use, has often been defined narrowly; with studies purportedly evaluating engagement mostly focusing on the impact of EVS use on student attitudes or participation in class. This practice was for example highlighted by a comprehensive review on EVS literature by Simpson and Oliver (2007). Further, I have to admit culpability because the initial studies that I conducted were more or less focused on an evaluation of the impact of EVS use on student attitudes and participation, although I highlighted how EVS use could also impact academic achievement and student feelings i.e. affective issues towards learning.

In the most comprehensive review of the student engagement literature to date, Fredricks et al. (2004) delineated engagement into three distinct yet interconnected dimensions:

'The multifaceted nature of engagement is also reflected in the research literature, which defines engagement in three ways. Behavioural engagement draws on the idea of participation; it includes involvement in academic and social or extracurricular activities and is considered crucial for achieving positive academic outcomes and preventing dropping out. Emotional engagement encompasses positive and negative reactions to teachers, classmates, academics, and school and is presumed to create ties to an institution and influence willingness to do the work. Finally, cognitive engagement draws on the idea of investment; it incorporates thoughtfulness and willingness to exert the effort necessary to comprehend complex ideas and master difficult skills.' *(p3)*

Fredricks et al. (2004) also indicated that 'many of the studies of engagement include one or two types (e.g. behaviour and emotion) but do not consider all three' (p26) forms of engagement. Consequently, I will be adopting the following three-dimensional engagement framework propounded by Fredricks et al. (2004) in evaluating the impact of EVS use on student engagement:

117

- Emotional Engagement i.e. how students *feel* about learning (liking);
- Behavioural Engagement i.e. how students *behave* in class (participating);
- Cognitive Engagement i.e. how students *think* in class (commitment or investment).

Learning issues that a high level of student engagement has been shown to have a positive impact on:
- Academic achievement   - Student boredom and disaffection   - Attendance and retention rates   - Attitude to learning   - In-class participation

Table 4.1 The impact of high student engagement on aspects of student learning[24].

4.1.2 STUDY SIGNIFICANCE

One of the conclusions of the comprehensive review of engagement literature was the need for 'studies of interventions' (Fredricks et al., 2004) that may help illuminate the 'development or malleability of engagement' to specific educational interventions. This study meets this need by highlighting the use of EVS and associated questions to facilitate emotional, behavioural and cognitive engagement within the disciplinary domain of university mathematics.

Further, the authors also called for the adoption of a qualitative approach to measuring engagement, which would provide 'thick descriptions of classroom contexts' about the factors that influence engagement (Fredricks et al., 2004). Again, this study meets this criterion as the descriptions of engagement provided are based on evidence from interviews with students, supplemented by classroom observations and observations of students working on specific tasks in the interviews conducted.

In addition, I will attempt to determine whether there is a correlation between EVS use and student achievement. This is pertinent because studies on educational

---

[24] Data drawn from Fredricks et al. (2004), Boyle (2001), and King and Robinson (2009b).

interventions to enhance engagement do not necessarily report associated impact on student achievement, if any.

4.2 EMOTIONAL ENGAGEMENT

In this section, I will be presenting the views of students, based on evidence from interviewee transcripts, on how the use of EVS has impacted their feeling, emotion or liking for (learning) mathematics on the module being investigated. Student views will be presented under several sub-dimensions or expressions of emotional engagement (also described as affect), including novelty, perception of learning environment, anonymity, relative performance, emotional reactions to answering EVS questions, and feelings about having to wait for others during EVS questioning cycles.

4.2.1 NOVELTY

The deployment of new or interactive technologies in new situations, whether for learning or other purposes, could be expected to evoke positive feelings due to the novelty of the technology. So it is pertinent to point out that the students whose comments about the emotional aspect of learning with EVS are being presented in this section are not new to the technology, having been taught in a first year university mathematics module by an instructor who used EVS in the class. Consequently, the novelty factor exerts much less influence on the feelings of students about EVS use presented here.

In the excerpt below, K7 (this is one of the 10 pseudonyms adopted for the 10 interviewees, as presented in Chapter Three) talks about how EVS use was introduced in a first year university mathematics module, and how s/he initially found the technology 'intimidating', but later became familiar with the technology because EVS was regularly used in class:

What did you like? Don't mention the names of the lecturers. What did you like about the two modules? What stood out for you, I mean, the way they lectured?

Um, they, um, the first one covered what I'd either done at A level, A level maths or Further Maths.

So it was an addition?

Yes. It was a nice break from the other subjects which were brand new, and it's nice to recap. Um, the second one was more new topics, which was nice, but also, um, we started using the voting systems from then.

Ok. The one on voting systems, the one on voting systems, so this is not your first introduction to voting systems...

No.

... so you've been kind of prepared for the use of voting systems.

Yes.

S/he also stated that s/he had talked about EVS use with peers from other universities who thought that classroom voting was a 'good idea':

Now that you're in the second year and using voting systems, have you got used to it in the sense that it doesn't really matter to you, you can play with it?

Um, yeah. At first it was a bit intimidating 'cause you didn't know, the very first question, you didn't know how it was going to work...

Yeah.

... even though you're pressing it anonymously and obviously, it was anonymous. It was just things going through my head. But once we started using them and I found them helpful, it was, the beginning of every class, pick one up and just use them throughout.

So what do you think - you used voting systems in first year, you're now using them in second year – how do you feel about this? Is it something you've welcomed, in the sense that part of your learning, I mean, you welcome it in a way now.

Yeah. I like it and I've mentioned it to people studying similar courses at other universities, and when I've mentioned that we vote in class, they've all been surprised 'cause they don't do it. And they've said it sounds like a good idea and it's definitely something I personally like.

Moreover, classroom observation of EVS use in lectures lends credence to the notion that student interest in EVS use appears to have moved beyond the initial or transient, 'situational' interest phase, based on the novel attraction of the EVS contraption, to a more stable orientation or 'personal' interest (Krapp, Hidi & Renninger, 1992). I am inferring this because students apparently still displayed positive attitudes towards EVS use, despite having been exposed to the technology for two academic years.

4.2.2 FAVOURABLE PERCEPTION OF LEARNING ENVIRONMENT

It appears that students have positive attitudes about the use of EVS in mathematics lectures (e.g. King & Robinson, 2009b). One reason for this is the perception of the learning environment, by students, as one that is intentionally designed for formative learning, with the sole purpose of helping students learn better. In the excerpt below, K2 stated that s/he usually took the EVS tests i.e. answering the questions in class seriously because 'that tells me where I'm standing in class', although s/he acknowledged that not all students emulated his/her approach:

And coursework too, if you do it well, it helps you with your final grade. But the questions that get put up in class, you don't want to get graded for that.

No, you don't.

So does that affect your attitude towards the questions? I mean, do you take them seriously or –

Yeah, I do take them seriously. Because that tells me where I'm standing in my class.

Yeah.

So if I don't do... if I don't take that seriously... Ok, there will be one or two questions you think 'ok, I don't know how to do it so I'll just ask him, ask my friend'. So there will be a few times when you think 'ok, I won't really vote for this' or you say 'I don't know'. But eventually, it, it tells you what you have to do. That's the main thing. 'Cause when you realise that you have to work harder, or you're doing well, you just go like this, so it's good, I think.

Yeah. That's very good. Yeah. What about the people around you. Do you get a sense that they have the same attitude you have?

Some of them do, some of them do.

Like they're serious.

Some do.

K4 also commented about whether EVS use had made any differences to the mathematics lectures. S/he submitted that the use of EVS in lectures makes the learning atmosphere 'better', 'fun', and 'a bit more social':

Ok. Because they use voting systems in C's class. What difference has it made? In terms of the structure, or the whole feel, the atmosphere compared to the other modules?

Um, it's kind of made it more fun because, like, it's more, like, you're involved as well. And, like, in some lectures, by the end of the lecture, you can actually look around and see people sleeping. But with C's lectures, like, because there's always a question or something to do, everyone's, like,

alert and awake. And, like, I think it's a better learning atmosphere. Like, I just think it makes it a bit more social as well, not constantly the lecturer talking and no feedback.

Similarly, K6 used terms such as 'helpful', 'reassures', and 'promoting participation' to describe the affective impact of EVS use on students:

'I have found the use of voting systems in MAB104 very helpful. Not only does it grant the user anonymity, but it also reassures you that, when you yourself may be struggling, there are others in the same situation. I also find it is a very good indirect way of promoting participation as there is no pressure' [all emphases mine]

In the same vein, K9 talked about how EVS use made classes more 'exciting' and interactive, and the fact that the technology reduces the burden of sameness that could be expected when lectures consist of copying down notes, week after week:

That's interesting. Do you have any other comments on the use of voting systems in class?

I don't think so. Just, they're really helpful. They make lectures more exciting, they give you something to do rather than just copying.

It gives you something to do. So –

I like interactive stuff.

Interactive stuff, ok. How is it interactive?

Um, well it's not just, sort of, listening to someone and copying down notes.

Yeah.

You know, you actually get the opportunity to think about it, know where you're going with it...

Yeah.

... it just makes it a bit more exciting.

It's more exciting. And you think maths classes are not exciting?

No, but sitting for an hour, listening to someone talk when –

Droning on and on?

Yeah. Not drone on, but, you know, even the most exciting lecturer, if you see them twice a week for an hour and it's copying down notes, it's not going to be exciting after eight weeks.

When I asked K1 about the disadvantages of using EVS, s/he responded by saying that his/her perception was that 'they added to the lecture more than anything' i.e. are beneficial:

... if you think about the classes you've had, what would you say are the disadvantages for using those? Any side, disadvantages or problems that you've noticed?

Um, not really, no. No, I just think they add to the lecture more than...

Yeah.

... more than anything.

They add... Say that again?

That they add to the lecture, that –

Similarly, research evidence suggests that students are more likely to refrain from cheating, and thus engage with learning when they 'felt their teacher was more concerned with student learning than certification via testing' (Palazzo, Lee & Pritchard, in press, as cited in Palazzo et al., 2010). In summary, a favourable perception of the learning environment is crucial to getting students to emotionally identify and align themselves with the goals and responsibilities expected of them in learning situations within that environment.

4.2.3 ANONYMITY

In class it was observed that, compared to a conventional class (see King & Robinson, 2009b), a greater number of students actively participated in class by responding to the EVS questions posed in class. One reason for this is that students could answer questions without their peers knowing how they answered or what choices they selected. This anonymity feature thus helps increase the confidence of students in volunteering answers to questions posed by the instructor. In the two excerpts below, K1 talks about how the anonymity aspect of EVS use helps with confidence and allays student fears about being put on the spot:

And this question says 'in what ways has the use of voting systems in MAB104 hindered or helped your learning of additional calculus?' And you said it helps you to answer anonymously, so nobody needs to know what you...

Yeah.

... how you answered. Why is that important?

Um, because you don't always have the confidence to put your hand up if you don't know whether you're right or not. But it lets you do it without anybody else knowing.

So she, before you did contours, she posed this question to kind of prepare you for how she was going to go on. And you think when she does that it kind of helps you.

Yeah, 'cause I think it triggers, it makes me remember –

Things you've done before and how to connect it with what you're going to do in the future.

Yeah.
Ok. Do you like that?
Um, yeah, yeah, I think it's good.

Or even, doesn't that put you on the spot sometimes? It's been so long, and then it's something you're also going to do in the future, so you might not have enough information.

It does. But because there's the anonymous handsets, it's ok. I wouldn't like her to do this and them come over to you and say 'right, what's the answer?'

'What's the answer?' **[At the same time]** *Yeah. Ok.*

Because that would put me on the spot. Because it's anonymous and also because she puts 'I don't know' there as well as an option...

4.2.4 RELATIVE PERFORMANCE

Students desire anonymity with respect to how they vote but interestingly seem concerned about how others vote. Moreover, they have access to this information because another feature of EVS use is that the answers to questions are usually displayed in the form of a suitable (e.g. bar) chart. So they can see how the class performed on a question. The EVS results display or spread thus performs two roles: It allows individual students to see their absolute performance on an EVS quiz. At the same time, the spread enables students to see how the rest of the class performed i.e. determine their relative performance.

In his/her submission, on the pre-interview questionnaire for instance, K1 talks about the power of the spread to illustrate relative performance:

'Allows you to answer questions to see if you are at the same level as the rest of the group'

K2 talked about how the knowledge about how the rest of the class performed on a test, based on the spread information, either enables him/her to work harder or feel good about his/her performance. S/he also mentioned that information about relative performance was critical because the class was very 'competitive':

So it gives you a kind of idea where you need to work harder?

Exactly.

It also lets you know how the class, the rest of the class is doing...

Yeah, how the class is doing.

Why is that important? You said, 'It lets you know where you need to work more', for instance – why is that important?

It's important that you... you know, if you're doing engineering, it's very competitive...

Yeah.

... so you always have to know how the other students are doing.

Yeah.

And by that you actually know, and then sometimes you actually feel good about yourself that you did well.

Right.

Yeah, if you're doing well, yeah.

Similarly, K4 alluded to the utility of EVS for illuminating relative performance on his/her entry on the pre-interview questionnaire:

'it gives you a chance to see how you are doing in comparison to the rest of the class'

During the interview K4 clarified the importance of having information about how the rest of a class performed on an EVS question, by commenting that access to this information would either bring reassurance or highlight the need to take corrective measures:

Ok. And this is a third question about use of voting systems. Everybody always says... I mean, most people say that it lets you see how you are doing in comparison to the rest of the class.

Yeah.

Why is that important?

It just, like, 'cause if you're constantly getting a different answer from everyone else, you're the one with the little bar going '4% answered this' and it's wrong...

Yeah.

... or then on the other hand, like, say, you're the right answer and only a few people have got it, it makes you kind of, like, feel good about where you are.

Yeah.

But like, in general, like, most of the time you all get the same answer and it makes you feel... it reassures you that you're, like, on the same pace as the rest of them. I think if you were struggling, say, if you were constantly getting a different answer to everyone else...

Yeah.

... it would make you, like... It's kind of anonymous as well, it would make you, it would make it easier for you to go and approach the teacher and say 'look, you know, I'm struggling here'.

K7 had also written about the importance of relative performance in his/her pre-interview questionnaire entry: '…helps see how I am doing compared to the rest of the class'. It seems that the motivation for having knowledge of how the class performed relative to a question is partly related to the presence of (healthy) competition in the class. K7 said for example that while students were usually happy to signify that they had chosen the right answer to a question, they did not display the same enthusiasm when they got it wrong:

... and then you can say 'what did you...?' Are people forthcoming when they get it wrong? For instance, if you've voted and you didn't get the right answer.

Some people take it as a, kind of, a joke. Like, they don't really mind. And others just, you always know when they got it right because they're really enthusiastic to say 'oh, I got that answer', whereas if they haven't –

They're kind of more evasive.

Yeah. They're, like, hoping not to be asked.

4.2.5 EFFECT OF GETTING ANSWERS RIGHT OR WRONG

It appears that when students get a question right in class, this tends to make them feel *elated*. In contrast, there is a feeling of *deflation* when they get a question wrong. Further, an awareness that most of the class seemed to have struggled with a question, provided by information on how the rest of the class performed on an EVS quiz, could help *reassure* students who thought they were the only ones experiencing difficulties.

In the excerpt below, K7 stated that the effect of getting a question wrong, when many of his/her peers correctly answered the same question right was to make him/her work harder i.e. 'I'll do that at home tonight'. In contrast, s/he usually felt elated when s/he got a question right that most of the class seemed to have gotten wrong. Moreover, s/he said s/he felt reassured when data from the spread indicated that majority of the class struggled with answering a question just as s/he did:

Ok. And what do you feel when, when there's something you thought you'd gotten, you understood...

Yeah.

... and then the question comes along that area, that subject or topic, and you struggle. How do you feel?

Um, I don't really know.

Yeah. Can you remember? Just cast your mind back to an experience in class, if you can recall any episode or –

Well, if, if the rest of the class seems to get it right, or most of them, then I feel a little disappointed that I haven't.

Yeah.

But I think it just makes me think 'oh, I'll do that at home tonight' or something. I don't really know.

Has it ever happened to you in the class where C put up a question and most of the class struggled with the question, but you got the answer right. How did that make you feel? Has that happened?

Yeah. It made me feel good that I was able to do it and see that. I don't know. It just makes you, not quite proud, but along those lines that I was able to do it and other people couldn't.

It helps with your confidence levels and it makes, it reassures you that you're doing, you're doing well.

Yeah. Yes.

What about this last part? You said it helps you see how you're doing compared to the rest of the class. Why is that important?

Um, because sometimes, um, not just in maths, in other subjects you feel you're struggling, and sometimes it can make you feel a bit down. But if you realise that everyone else is feeling the same...

Yeah.

... how everyone's feeling, so it's, in a way, normal, so you've got nothing to worry about if everyone's feeling the same.

Similarly, K9 said that when s/he got a question, especially a tough one wrong, this had the effect of highlighting the problem and motivating him/her to work on addressing the gap in understanding:

Ok. So, what about when you've got a hard question you can't solve, how does it make you feel? Do you have any feelings about it?

Um, it kind of annoys me, but I, I like the fact that she does questions like that because then I know that I'll go, I'll go through with it and what I need to work on.

Where you need to work on [Interviewer and interviewee said this at the same time]. Yeah.

Whereas if there weren't any questions at all, then I'd be quite content with the fact that I don't really know but I don't know what I need to work on.

Why does it annoy you?

Um, it annoys me because I know I should be able to do it. Or even if I don't know how to do it I should roughly know where I'm going with it. So sometimes it annoys me if I haven't got a clue...

Ok.

... where to even begin.

In contrast, K9 stated that being able to answer a question correctly makes the effort s/he puts into attending lectures 'worthwhile' and also signified that s/he was making 'progress':

What about if a question is easy? How do you feel?

Um, a lot better actually. It's nice to know that I can, you know, if I can do the question.

Yeah.

It's nice to know that it's worthwhile going to the lectures and it's, I'm actually making some progress.

During the interview, I asked K9 to work out the answer to Q2 and initially s/he was unsure about how to proceed. When I confirmed that the answer s/he provided was the correct one, s/he was visibly delighted. I asked him/her about this experience and s/he again reiterated the point above about how getting a question right makes the effort s/he puts in worthwhile:

Yeah, so that's a good thing. So, if it's, if you're in the class and C puts up a question, and you're not sure about what your answer is and then it comes, and the answer happens to be what you chose. It makes you feel the same way you feel now? [I recall that I made note at the time of the fact that s/he was visibly delighted that s/he was able to answer a question i.e. Q2 during the interview that s/he had initially struggled with]

Yeah, yeah.

Ok. How does, is that, why is that important?

Um, because if, if you get it wrong every, every time, it's quite, you feel quite defeat, not defeated, but...

Yeah. It's not –

... 'what's the point in going to lectures and tutorials all the time if I'm going to get all the answers wrong?'

Yeah.

Whereas it's quite nice...

If you get –

... if you get it. Or even if you think 'I think it's that one', so...

K10 referred to the effect of having questions that s/he found easy to answer as 'always good' and confidence boosting:

What do you do? First of all, what do you, how do you feel about that? An easy question, how does that make you feel?

It's always good, because you've got, you've got something right, or you feel you have, so it's...

Yeah.

... it kind of boosts your confidence slightly. And I suppose, there's that, there's that time afterwards when you're just sat around doing nothing and just, like, tapping your fingers.

4.2.6 WAITING FOR OTHERS DURING EVS QUESTIONING CYCLES

Having observed in class that students often spent less or more than the time allocated for a question, I wanted to find out what those students who answered a question quickly and still had time to spare, did to occupy themselves during the interval. In the excerpt below, K1's response indicated that s/he spent most of the interval being (largely) distracted:

That's very good? So what do you do after they give you say, 30 seconds, 45 seconds to answer a question and after 3 seconds you already know the answer and you click it. What do you do for the rest of the time?

I just wait and look at people and what they are doing.

K4 stated that s/he found the waiting time 'annoying'; although s/he countered that there would have been times when others had to wait for him/her too:

Ok. What about if it's too easy? You know, other times where you're given 40, 50 seconds and then three seconds – you've got it.

Yeah. Sometimes that's a bit annoying because you're sitting around waiting. But, I mean, it's kind of the flip side of the last question. It's like, you know, I'm sure there's times where people will be waiting for me, so... It's just what your strengths are, I guess. Like –

So you find it annoying when you have to wait for the others?

Oh, I'm just impatient. I'm like 'oh, come on'.

K5 stated that s/he usually felt that it was a waste of his/her time when s/he found a question easy, although s/he also indicated that others might have found the question that s/he found easy, difficult. In contrast, s/he said that if the question was hard and s/he still had time to spare after inputting his/her answer, s/he would spend the remainder of the time to recheck his/her work:

Like I said, you've already told me about when questions are hard, what you do. What if the question is very easy? Like if she gives you 45 seconds, 50 seconds to try and answer the question, and you just take 3 seconds to answer. How does that make you feel?

I feel like I wasted my time.

Because it's not worth it, right?

I suppose it doesn't matter. If it's easy to me, it may not have been easy for the others.

Forget about the others for now. So you feel it's not worth your time because you have to wait for the others and for the polling to close?

Yes.

Yes, so what do you do in that time where you've already submitted your response and other people are still waiting for other people?

I suppose you have to wait, yes.

And what do you do within, during that time?

I just have to wait.

So how do you wait? What do you do while waiting? You just fold your arms and look around?

I don't know, it depends. It depends what's going on 'cause if it's a very easy question and I know I got it correctly I'll just leave it and wait, and if it's something that I'm not quite sure about...

Not quite sure about... [At same time]

... and the voting is still open I might...

Revise or check? [At same time]

... yes, just check it.

In summary, student submissions suggest that EVS is no longer seen as a new or exciting piece of technology. Therefore, the influence of EVS use on emotional engagement, as presented in this section, may be construed as being devoid of the novelty effect. The fact that students are able to answer questions anonymously has an enormous impact on the numbers of students responding to questions in class. Anonymity helps remove or reduce the fear of being labelled stupid or being embarrassed in front of peers, in the event of getting a question wrong. Student submissions also indicate that they often experience a feeling of elation when they answer a question correctly, and deflation otherwise. However, student comments indicate that having to 'wait for others' during EVS question-answer sessions often lead to distractions – which is an expression of student behaviour in class.

In the next section, I will present evidence from interview transcripts on the impact that EVS use has had on students' behavioural engagement.

4.3 BEHAVIOURAL ENGAGEMENT

Based on data analysis, three aspects of behavioural engagement were identified as having been influenced by EVS use. These are: Participation, Attention and Interactivity. In this section, I will present evidence, from interviewee transcripts, on the impact that EVS use has had on these three facets of student engagement.

4.3.1 PARTICIPATION

Classroom observations and empirical research into EVS use at Loughborough University (see King & Robinson, 2009b,c) and at other institutions (e.g. Boyle & Nicol, 2003; Draper & Brown, 2004; Duncan, 2005; etc) present compelling evidence that EVS use increases student participation – strictly from the perspective of responding to questions in lectures. Hence this aspect of behavioural engagement will not receive further mention in this section, the concept having reached a level of theoretical saturation.

4.3.2 ATTENTION

Attention plays a pivotal role in mathematics discourse. Various researchers have examined, for example, the role of attention in helping students learn algebra via specialised computer software (Hewitt, 2009) and the interplay between attention, instructor pedagogical practices and student engagement with the learning process thus engendered (e.g. Mason, 1989; Ainley & Luntley, 2007; Wilson, 2009). In this section, I will illustrate how EVS use may, and have been, used to help *stimulate*, *maintain* and *direct* student attention in class in the following three ways:

1. EVS use makes students pay attention during a lecture because they know they are going to be asked a question, usually about the topic presented in class. Hence EVS use may help *stimulate* student attention.

2. EVS questions may be used as a way of managing a lecture by presenting the questions at carefully selected intervals in order to defuse boredom and monotony. Hence EVS use may help *maintain* student attention.

3. If a student had not been paying attention prior to the administration of a question, this serves as a wake-up call to the student i.e. highlights the

inattention and also what is required to remedy the situation. Hence EVS use may help *direct* student attention.

4.3.2.1 Stimulating Student Attention

In the excerpt below, K9 talked about how the sight of EVS handsets at the beginning of a lecture and the association of the handsets with questions to be asked in class created a feeling of 'anticipation' or eagerness about the lecture. In fact, s/he prefaced this by implying that the atmosphere or ambience around a 'voting system lecture' was remarkably different from conventional lectures in a positive way:

Yeah. Not drone on, but, you know, even the most exciting lecturer, if you see them twice a week for an hour and it's copying down notes, it's not going to be exciting after eight weeks.

How does voting systems change that? How does, how does, the use of the clickers change that?

You can tell when, you can tell when we've had, like, a voting system lecture, because everyone comes into the room and sees the voting system. And everyone's sort of a bit more on edge, and, you know, anticipation about, 'oh, I've got to pay attention because, like, there's going to be a question coming up'. Whereas before, it was just, like, 'oh, I'm just copying down this note, and the next note, and the next note' [emphasis mine].

Ok.

So it definitely makes a difference.

K8 also talked about how EVS use made students 'focus on the lecture', and contrasted this with the scenario in other lectures where students were in the habit of falling asleep in class (and implied that this did not happen in EVS-enabled lectures):

And another comment here – you said that this ensures that most students in the class focus on the lecture.

True.

How does that happen? I mean, why, how do voting systems make that happen?

Mm, when you compare a similar scenario…

Yeah.

… with another lecture where they don't use voting systems…

Yeah.

… people just come to the lecture and sleep, you know? To be honest.

Yeah.

And during voting systems, at least that doesn't happen, you know? Even if they're not listening when the lecture's going on…

Yeah.
… when they see a question…
Yeah.

… they start working it out, you know? As in, they start, you know, on the paper, the start something, you know?

Yeah.

So it's better than not doing anything at all.

Ok.

K1 talked about how the EVS question-based instruction approach on the module 'makes sure that you're alert':

I see. Is the class more interactive? MAB104 – is it more interactive than your other modules?

Yeah, yeah. 'Cause the other modules, I suppose, they just stand and talk to you, whereas this, they ask you questions...

Yeah.

... and it makes you, makes sure that you're alert.

4.3.2.2 Maintaining Student Attention

There is evidence to suggest that it is hard to maintain attention, within the context of a lecture or presentation, beyond 15 to 20 minutes at a time (Middendorf & Kalish, 1996; BBC, 2010); although Wilson and Korn (2007) disputed the supporting evidence, but not the reality of the attention span itself. Moreover, the current generation of students also known as digital natives, or the Google generation are notorious multi-taskers (e.g. JISC, 2007; Oblinger, 2008) who find it difficult to concentrate on any one thing or task for a considerable length of time.

However, it seems that EVS use, especially when the questions are spread throughout a lecture, may help maintain student attention. In the excerpt below, K4 talked about how the timing and the use of EVS questions helped 'break the lecture up

a bit', and how this helped his/her concentration in class or to put it another way, got 'his/her mind active again':

In terms of concentration in class, sometimes the lecture, in mathematics especially, you can have a 2 hour lectures or an hour lecture. Let's say it's a 1 hour – it's hard to concentrate from the first minute to the last minute. You lose concentration. Most people do. Does voting systems help you concentrate?

They break it, they break the lecture up a bit and I find, that obviously your concentration can then be distracted away from the visual, from learning on the board. And then you can actually do something, do something yourself...

Yeah.

... get your mind active again and then obviously you can listen for the next 20 minutes again.

So it helps in that way – to break the lecture into chunks?

Yeah.

K7 stated that the use of EVS questions meant that 's/he can't just switch off for the whole lecture' and also implied that, as s/he often felt that student work was being somehow monitored, s/he was inclined to stay motivated and concentrate on the work at hand:

When you have voting systems and a question comes up and...Does that make you actually, like you said, some places don't use voting systems, but when C uses voting systems to answer questions, does that make you think more about the question, solving the question?

Yes. Um, I feel it's harder to just let the lecture information just go over your head because you're being asked a question about it, so you've got to think.

Yeah.

You can't just switch off for the whole lecture, you've got to think and... You always feel, even though it is anonymous and no-one knows who said what...

Yeah.

... you always think that someone, the lecturer is looking to check who's actually working or not.

Ok.

So it makes you, well, it makes me work more.

Yeah. You said it helps you, you can't just switch off – you said something about not switching off. How does... Does the use of voting systems help you to get, to keep switched on during the class?

Yes.

135

Similarly, K2 also talked about how s/he had a problem 'concentrating for more than 10 minutes':

And then you just struggle with it. This has happened to me a lot of the time as well. And I have this... I have this certain problem... I don't know if... I have a major concentration problem for concentrating for more than 10 minutes or something.

Ok.

My mind just wanders off somewhere. So it might be like that – some people weren't concentrating at that time properly...

Yeah.

... so it's the same for me, I wasn't really concentrating at that time. But I was actually kind of concentrating on this so I just figured it out.

K2 went on to say that s/he found that the usually limited time allocated for voting often helped him/her to concentrate on a question in order to get the right answer:

Ok. Talking about that – it's a very good point – concentrating. Sometimes when you go to this lecture and the man or the woman at the front just comes and rambles on and on and people just switch off sometimes. Maybe just think about something nice... Like soccer.

Yeah. That happens a lot.

So you're not really tuning in at that point?

If the lecturer is very boring...

Monotonous.

Exactly. If it's the same thing. And if... I'll tell you, our mechanics lectures – they are not the most interesting and the lecturer is not the most interesting so it's very hard...

Very hard. [At same time]

... to concentrate.

Coming back to here, how does voting systems help you? How does it help you with concentration? Do they help, or...? The reason I'm saying this is because she likes...

It can only help for you to concentrate. Because the thing is you know that you're being given 30 seconds to solve this, for example.

Yeah.

You're being given 30 seconds and you have to concentrate and then you have to vote. So it is related. 'Cause you... Because of the time limit you have to concentrate on the question and then you have to vote quickly so that you get it right.

Yeah.

So that's the only one I think.

Last, K1 implied, in a positive way, that the instructor often deliberately asked students questions just 'to make sure you've been listening', in order to ostensibly maintain student attention:

... so people don't actually know what your answering. That's one benefit. The other benefits – you also mention it makes you alert during the lecture.

Yeah. It makes sure you've listened to, um, what they've said and...

Yeah.

... cause, is it C [i.e. instructor name]?

Yeah, C. Yeah.

Yeah, just at any time during the lecture, she'll just spring us, bring a question up, so, to make sure you've been listening.

4.3.2.3 Directing Student Attention

In the excerpt below, K4 talked about how getting a question wrong was a sort of reality check that brought home the message, 'I actually haven't listened at all today', and how this tended to make him/her feel more accountable about paying attention in class:

When you answer a question, sometimes I see, I've been in some classes where I see some people talking to each other sometimes, just before, or even after. Has that happened to you?

Yeah. I generally talk to my friends. It's not always about maths, but, like, it's like 'oh, what did you get, what did you get?', like, if I'm stuck, like, I don't understand, like...

So it gets you talking at that point?

Yeah.

And usually, when you talk at that point, it's more, like, going to be about maths and not about Eastenders?

Yeah, it's quite good actually. Like, I hate sitting and not talking for any length of time, really. So it is good to kind of have a little break in a way.

137

Ok. So are you enjoying talking now? Because sometimes, I get the sense that, you know, people are questioning you, like an inquisition.

I like talking.

And when she gives you a question where you have to think about the answer, how does that help you? You know, like you said, some of the other lecturers, they don't give you questions, they just drone on and on...

Yeah.

... but this one, you're given a question maybe after she's just done a topic and she wants to find out how well you got it.

Yeah. It makes you realise, like, if you've actually been listening or if you've just been sitting there, and, you know, on auto-pilot. And, like...

Yeah.

... sometimes when she's put a question up, I'm like 'I actually haven't listened at all today'. Like, what am I doing, why am I here if I'm not going to listen. Like, it kind of makes you, like, it kind of holds you accountable in a way, like, your attention span.

Getting a question wrong in class seemed to have the same effect on K7 as it had on K4. K7 stated that getting a question wrong would make him/her think, 'I should have paid more attention'. However, s/he pointed out that this was usually followed by the desire to make up for the inattention by reviewing his/her notes alongside the feedback from the instructor:

What about, if before a question came up, for one reason or another, you were switched off and thinking about something else. You were not paying attention to that particular topic and a question comes up – what happens?

Um, I always think 'I should have paid attention', but then it helps because I'll have to look through the notes I've taken, and if I still don't quite get it, then C will go through it and then, it just makes it really...

Yeah. What about if you, you see a question and you can tell from looking at the question you don't know what to do? And, um, do you go ahead and attempt the question or do you wait for C to, wait for C to, for the polling to close and then C can provide the answer?

I give it a go, even if it's, 'cause we do have the option to say 'I don't know'. But I'll give it a go and try and not write notes. But sometimes if you don't know how to do it, you haven't got time to go through all your notes to do it.

4.4 INTERACTIVITY

Interactivity in EVS-enabled lectures refers to the use of questions to actively engage students in the learning process, instead of them being passive recipients of information transmission from the lecturer. Based on the classroom observations that I have made and evidence from interviewee transcripts, which I will be presenting later, EVS use has the potential to catalyse two levels or modes of interactivity in mathematics classrooms. These interactivity modes are:

Surface Interactivity: This is the interaction between student and instructor i.e. instructor poses a question which students respond to by answering, and which the instructor then responds to by providing feedback. This sets up a chain of interactivity between student and instructor, which is not a typical feature of contemporary university mathematics lectures. But this occurs at the surface level because the mode of communication is limited, and mostly instructor-driven and/or initiated.

Peer Interactivity: This is the interaction between students. Class observations show that this interaction occurs when students compare their answers with their neighbours after voting, talk through a problem with a friend before voting, or in a limited sense, on the few occasions when the instructor asks the students to discuss their answers with their neighbours.

There is a third level of interaction, which may be referred to as **Technical Interactivity**. This may be defined as the interaction between the system and the RT device – the students get to 'do something', although this usually translates into merely clicking a handset. Its significance might be that the physical action of a clicking a handset could perhaps help reignite student interest or attention. As this form of interactivity, has a limited impact on behavioural engagement, I will not be presenting evidence of this interaction mode.

4.4.1 SURFACE INTERACTIVITY

In the excerpt below, K8 talked about how the use of EVS 'changed' what usually happens in a mathematics lecture, in that students had the opportunity of interacting with the instructor, via the EVS question and answer sessions:

... so hold that thought. Number 3, the question number 3 says, I wanted to know what benefits or problems voting systems have caused you on your MAB104 module. And you say here that it's helped your revision of calculus and it's, it has changed what usually happens in a lecture.

Something different, yeah.

Something different.

Yeah.

Why is it different?

Because of the others' interaction, you know? There's interaction between the students and the teacher.

What kind of interaction?

Um, answering. Like, what basically happens if she asks a question...

Yeah.

... we'll be asked to answer.

Ok.

So, directly, we may not be answering, but we use the voting system.

You've got that contact to give a response back.

Exactly.

So, that doesn't happen in other lectures?

No, it doesn't. Very few.

Ok.

It's only when a person raises an arm and asks a question is there interaction between the student and the teacher.

K5 had also written on the pre-interview questionnaire, that one of the ways that EVS had 'helped' was that it provided an avenue for 'more interaction with the lecturer'. More evidence for surface interactivity is not presented here because research evidence (e.g. Boyle & Nicol, 2003; Draper & Brown, 2004) clearly indicates that this is the most common form of interactivity enabled by the use of EVS.

4.4.2 PEER INTERACTIVITY

The instructor would often encourage students to talk to their peers in order to challenge one another about the rationale for the answer choices selected in response to

an EVS question. However, the instructor would typically only instigate this kind of discussion when the class response indicated a lack of consensus e.g. a question in which only 50% of the class got it right, as K9 describes in the excerpt below. It should be noted that in this particular class, students often sat with their friends, and so peer interactivity in this context is contingent on existing group dynamics. Students were more likely to chat with their friends knowing that they would not be ridiculed or embarrassed if their knowledge of the mathematical topic under discussion was below par:

Um, and occasionally, you know, if, sort of, if it's been a majority vote, then she'll say 'oh well, you know, that, 90% of the class voted for that'...

Yeah.

... and then we'll go through the question and say 'well, yeah, 90% were right'. Whereas if it's more sort of 50/50, then occasionally she'll say 'ok, who voted for this, who voted for this and then talk amongst yourselves...

Yeah.

... to sort of try and convince the other person why it's that one'. And then we'll go over it so you know roughly why, even if the answer was wrong from your part, then you'll know why the other person thought that answer was right or... So it's quite, it's quite good talking about it every now and then, 'cause even if the answer's wrong, you know why someone would have voted for that.

Ok. So C sometimes asks you to talk to your neighbour and say 'convince him or her why your choice was right or wrong'.

Yeah.

What, how did you feel about that? How did you find that? 'Cause I –

Um –

Yeah?

I found it, mm, quite helpful because normally I sit with my friends, so even if my answer's wrong, it didn't really matter.

Yeah.

Um, I don't think it would work so well if, you know, you're split into groups or anything, because I don't, I know other people in my class, in my group are cleverer than me, so it's not always nice knowing that they're always right and you're always wrong.

They're always right, ok [At the same time].

But when you, when it's with your friends, it, it's quite nice to think 'oh well, they voted for that one for a reason'...

Yeah.

... and, yeah.

A feature of peer interactivity is that some students sometimes talked with their peers before submitting their vote. In the dialogue below, K2 described how s/he would often ask his/her friend (s/he often sat with this friend whom s/he had described as being 'smarter' than him/her) to show him/her how s/he solved a problem. The disadvantage of this approach is that K2 admitted that s/he would often select the answer provided by his/her friend as his/her own. However, s/he claimed that s/he would usually ask his/her friend, after the lecture or in a tutorial to explain how s/he solved the problem (however, I am not certain s/he would have been able to do this in every instance):

Yeah. So we were talking about sometimes the question's too hard and you can't do it...

Mm hm.

... and you said that you either talk to your friends or go to the tutorial.

Usually I'm sitting with my friend... if a difficult question comes up...

Yeah.

... I would consult him. I will ask him, 'how have you done it and what's the answer?' and he'll, like... it's a brief discussion on how have you done it. And then, if he knows how to do it and he gets the right answer, I'll ask him 'how are you doing it, man? Tell me... show me how you did it'. And then he shows me and that's it. And in the lecture, I can know... I eventually find out how –

How to do it?

Yeah.

That's very good. But what the problem is, you do it both before and after. Like if the question is hard you... first of all you try to work it out in your head...

Yeah.

... and you say 'this is hard'. And your friend, you can see, maybe look around and he's getting the hang of it so you just ask him 'what's this answer, what are you doing here?'

Well, if the steps are long, obviously you don't ask him right, like, there 'show me how you did it'.

Yeah.

But what you do is get the answer and you just vote for the answer just to get yourself right...

Yeah.

... but then you ask him later, ask the friend later, then, how you did it. Or if there's a tutorial after the lecture, you go to the tutorial and ask the –

What do you usually do?

I usually ask the friend.

And does that usually solve your problem?

It does.

Generally, most interviewees appeared to talk to their peers about the EVS questions, only after they had worked on a problem and submitted their own answers. K5, for instance, describes how s/he would vote and afterwards ask a peer, 'what did you get?' S/he also alluded to the group dynamics inherent in the classes where 'it's usually small groups of us [i.e. friends] sitting together' and 'looking at each other's work' to discover if anyone had a different answer and probably talking about why that was so:

Are there times when you vote, you know, sometimes people are afraid of something, someone around you. Are there times when you vote, like, before you vote, you check with your friend or colleague or peer... whoever's seated around you and say 'what's your answer?'. Do you do that?

Uh, yes. I suppose, yeah, we do that sometimes.

Do you do that?

I think I've done that yes.

Checked the answer before and asked 'what did you get?'. So, before or after or both before and after?

Um, usually I would vote first and then ask them 'what did you get?'

It's ok to do it before because it's not an exam.

It's not an exam, yeah. [At same time]

Coach. Collaboration. Do people actually discuss before they submit their responses? Because in many ways in maths, most people just tend to be... it tends to be personalised in a sense that it's individualised. It's just me and my maths.

143

Ok.

I'm not talking about with other people. If it's philosophy or some other engineering-like project-based stuff, you have to talk with other people, collaborate...

Yes. I think most of the time what tends to happen in our lectures is – I don't know whether it's just us – but it's usually small groups of us sitting together...

Yeah.

... usually we would answer and then, um, if one of us, or if we get a different answer, we look at each other's work and work out how, you know, who has gone wrong and why.

K10 also talked about how s/he would vote first and only then talk to his/her peers to avoid being influenced:

Are there times in class when you wanted to vote, you talked to the guy sitting next to you or the guy sit, your mate or people who seem to be close to you before you answer the question or after you answer the question?

Um, I think, you kind of, I go and answer it first, and if you talk to somebody else, in case you can change it, you've always got the option of –

So you're just asking 'what have you got?'

You're, like, being influenced by other people.

Ok.

Yeah.

It should be noted that although some level of student-student interaction i.e. students talking to each other in class occurs at least sporadically in most conventional mathematics classes, EVS use assures a higher frequency/structure and more learning-focused occurrences of this type of interactivity. In the excerpt below, K9 stated that although s/he usually sat with a group of friends, s/he would 'normally' vote first, and only talk about how s/he voted afterwards with his/her friends:

So, but, let's say you, when... I just want to know what happens sometimes, classroom dynamics, you say that you sit with a group of friends sometimes. Do you check your answers before you click or after you click, you know, with each other?

Um, normally –

Just think back. You're in the classroom now, maybe with one of your –

Normally, normally we'd click...

Yeah.

... and then, like, talk to the people next to us and say 'oh, I got, I said B'

I figured it out, yeah.

Um, but normally we vote and then...

Yeah.

... talk about it afterwards.

Joint Voting: K9 also indicated that s/he and 'the person I'm sitting next to' would sometimes vote jointly, using a single handset in cases where s/he could not get a handset due to going to a lecture late:

Yeah. Were there times where you got late to class and you couldn't collect a handset before, um, the time?

Yeah.

So that means...

Um.

Yeah.

It's, it's not so bad because that way I just, sort of discuss it with the person I'm sitting next to...

Yeah.

... and say 'well, I think it's that one' and then, we come to, like, a joint conclusion.

Ok. Did that happen after?

Um, a couple of times.

In the dialogue below, K6 implied that students who got an answer wrong would often ask their more knowledgeable peers how they got the right answer, after the display of the results of the voting exercise:

Ok. That makes sense. It was 16, and most people, most people got... Do you have any, any comments on the spread – how many people got it right, how many people got 48?

Um, I'm not quite sure how they got 48. That's quite a high –

145

You can't understand how someone can put 48. Now, 17 people in the class got 48.

Yeah. I'm just hoping that that wasn't me. I don't know what I would have done.

So what does that mean?

That means most people understand it, um, and –

When you're in the class and you've seen that, let's say you've just voted. Forget about how you voted. What were you thinking, based on that spread?

Um, most people know it. Most people have understood. The other people would probably ask the people sitting next to them and go 'oh yeah, that's really obvious now'.

Challenge: There might also be an element of challenge involved in the voting. In the excerpt below, K4 talked about how s/he would often wait impatiently for the instructor to close the polling and for the results to be revealed because of his/her anticipation or excitement at seeing whether s/he got the answer right. Similarly, s/he talked about how s/he would ask for the answers that his/her friends selected as a sort of competition to see whose answer would be revealed to be the right one:

So you find it annoying when you have to wait for the others?

Oh, I'm just impatient. I'm like 'oh, come on'.

'Come on, get a move on'.

I want to know if I got it right or not, you know.

Yeah. Ok. So there's anticipation to know whether you got it right or wrong.

Yeah. It's exciting, it's like, 'oh god'.

'I'd better get that right... how the rest of the class do?'

Yeah. I'd be like 'I got that right, yeah'. Or, like, before your friends are done, you're like 'what did you get or what did you get' or you've got two different answers, it's like 'I bet I'm right, I bet I'm right' and it's like 'yes'.

K8 also talked about how this element of challenge when s/he stated that s/he would often ask his/her friend, after voting, about the answer s/he had selected 'just to see if s/he was right or wrong':

Ok. After you've voted, you don't ask them to see 'what did you get, do you, what was your answer?' You don't, you don't usually ask?

Um, before the answer comes up or after the answer comes up?

Before or after.

After, I do.

You do.

After. When it, suppose we get 75% for A and 35% for B...

Yeah.

... or something like that, you know?

Yeah.

Then I'll ask the person sitting next to me what he got, you know? Just to make sure, just to see what he would have thought, you know?

Yeah. And that's –

Just to see if he was right or wrong.

Ok. Why do you want to know that?

Just 'cause he's my friend, so –

In summary, EVS use has been shown to facilitate increased student participation in mathematics classes. Further, student responses indicate that they are often alert when they are in an EVS-enabled lecture *because* they know they will be asked questions which they could only answer if they pay attention in class. EVS thus helps stimulate student attention. Further, evidence suggests that EVS use also helps maintain student attention due to the spread of questions across the lecture hour to prevent boredom and to serve as natural breaks for students during a lecture. Similarly, EVS use also served as a reality check for students, a gauge of how attentive they were in a class, as measured by how well they responded to the questions. This subsequently serves as a way of directing or re-focussing their attention in class. The use and timing of EVS questions thus play a major role in facilitating student attention.

Another facet of behavioural engagement that EVS use has influenced is the level or mode of interactivity in lectures. The question-and-answer sessions provide a level of instructor-student interaction that is otherwise absent in typical mathematics lectures. Moreover, the question sessions are often structured in a way that allows students to interact with each other. One expression of this is that students may submit a

joint vote after discussions. Another is the element of challenge that peer interaction introduces into classroom dynamics i.e. students want to see if they can do better than their peers.

In the next section, I will present evidence from interview transcripts about the impact of EVS use on how students think or reason in class.

4.5 COGNITIVE ENGAGEMENT

Students may appear attentive in class and be conscientiously copying notes, but this does not necessarily mean they are 'cognitively engaging' with the material (Hamilton & Hurford, 2007). But giving students questions to attempt in class tasks them mentally and requires them to recall and apply the facts and knowledge they have accumulated on a subject. This is an expression of deliberate practise: In deliberate practice, a student works under a tutor (human or computer based) to rehearse appropriate practices that enhance performance (Bransford et al, 2000, p175-176). In this section, a selection of interviewee comments about how EVS use enables deliberate practice (Bransford et al, 2000), which in turn facilitates cognitive or meaningful engagement with lecture material will be presented.

4.5.1 DELIBERATE PRACTICE

It has been observed that it is sometimes difficult for students to take notes in a lecture and simultaneously mentally process the lecture material. What frequently happens is that students somehow mentally disengage from the material while copying notes; a phenomenon referred to as the students becoming 'human copy machines' (Hamilton & Hurford, 2007). However, the use of EVS questions in a lecture gives students the opportunity to pause and reflect on the material previously presented in a lecture, so they could utilise information from the lecture for answering the EVS questions. In the excerpt below, K10 talked about how s/he found it hard to 'actually listen to what the lecturer's saying while I'm writing down'. S/he added that the use of EVS questions gave him/her an 'idea of what's going on' with respect to the lecture content:

You say 'it's helped my progress as in lectures, as in lectures we're required to take a lot of notes and I find that I don't take in much information, concentrate much'. 'The main thing is that the voting system gives me time to read over the notes and it helps me get to grip, to grips with the topic faster'.

Yeah. Like, it's like, 'cause we're writing down notes constantly, almost constantly...

Yeah.

... I find it hard to, um, actually listen to what the lecturer's saying while I'm writing down.

Ok.

So I don't really take in that much. So when we have the questions, it gives me time to read over it and actually, like, have to put it into practice, so I...

Yeah.

... like, instead of going away from the lecture and reading over my notes...

Yeah.

... I kind of have an idea of what's going on.

Further, K9 stated that whereas in the past s/he had revised by reading through his/her notes and found this unhelpful - see Chapter Five (Section 5.7) for my characterisation of K9's approach to learning, s/he found the EVS questions very helpful because s/he could monitor his/her understanding, and progress with module content. S/he also pointed out that the instant feedback received after question and answer (QA) sessions meant that s/he could make necessary corrections while the topic was still fresh, as opposed to the conventional practice, especially in summative assessment, of giving students feedback two to three weeks after they had completed the assessment:

Ok. This is the question where I asked about how voting systems have helped or hindered your learning on the MAB104 module. And you say it helped – you said 'it's very helpful as I could see how I was getting on but also going through it there and then answering the questions, refreshing my mind'. You say that it helped you to see how you were getting on – what does that mean? What do you –

Um, I used to revise just by reading through my notes...

Yeah.

... which was, which never gave me a real idea of how I was getting on.
Yeah.
So with that I could see if there were two similar answers, then I could see 'well, I'm roughly on the right track because I got one of the two' even if it was the wrong one.

Yeah.

So I knew roughly where I was going with it, or 'well, I got completely out' so I knew, it was a lot easier, I knew where I was and how I was getting there.

Ok.

Um, and also because it wasn't a strict test, so even if I got the answer wrong, I didn't feel bad about it because I knew no-one else knew, she would go over it...

Yeah.

... and I'd understand it. And it was, she went over it straight away, so you, you could find out the answer there and then rather than, with a test, where the test goes away and you find out how you've done badly and then you feel bad about it and then you get the answers back a couple of weeks later, and then you can't remember.

In his/her pre-interview questionnaire entry, K9 stated that EVS use was helpful in that it enabled him/her to solve problems while the topic was still 'fresh': 'Helped! It is very helpful as I could see how I was getting on but also going through it there and then so the question is fresh in my mind.' Similarly, K4's questionnaire entry echoed K9's comments: 'I think it is really useful because it means you get a chance to try it out for yourself [a problem that is] before you get home and then the lecturer can go through mistakes'. K5's entry also emphasised how EVS use made students work more and harder on questions while the related topics were still fresh in their minds: 'More examples covered during lectures; Made me work/try harder during lecture to answer questions confidentially'.

The usual practice of the instructor on the module being investigated is that she would introduce an example of a concept and then, if appropriate, give the students a related EVS question to answer. K1 commented that having to do a question made him/her *think* about what the instructor had said in a lecture:

So, I'm trying to see, when a question comes to you like that in a lecture, what does it necessitate from you? Does it make you think more?

Yeah, yeah. It makes you think about what she's just said...

Yeah.

... and, like, look over... 'Cause she's normally just done an example with us all and then she'll ask you...

Ok.

... like, a question on it.

4.5.2 DELIBERATE PRACTICE (INTERVIEW CONTEXT)

Apart from classroom observations, I also had the chance to observe how deliberate practice would often help students to concentrate and apply what they had learnt to solve a problem. In the interviews, I presented the students with at least six questions (from a base set of 18 EVS questions), which they had to answer, or provide an explanation of how they would solve the problem. As has been stated earlier, these questions had all been used in class. Sometimes, the students were initially unable to answer a question. But I discovered that when students concentrated or asked for more time to answer a question, they frequently came up with the right answer or approach.

One example is K5 who initially said s/he could not 'remember how to work out grad φ' (see Figure 3.6). But because s/he was still focusing on how to solve the problem s/he later recalled how and when s/he did, s/he stated: 'Hang on, it's coming back to me now!':

Right, so the next one. Do you remember this question?

Not really, no. Oh yes, yes, yes.

Why do you remember? Are you sure you remember now this question?

Yes, now I remember it.

Why did you remember it? What made you remember?

Sorry?

What made you remember?

Um. Probably working out grad phi.

Grad phi?

Yeah.

Was it because you did it with voting systems or because you did it as part of the lecture?

It was because, probably, we did it as one of the last things we did.

Ok.

Yeah.

And if you wanted to solve it, how would you go about it?

I can't remember how to work out grad phi.

Is it going to be a scalar or vector outcome?

It's got to be a vector, isn't it?

I don't know. [At same time]

It's going to be a vector, yeah, it's got to be a vector. Hang on, it's coming back to me now. Oh yeah, yeah I know how to do it now. 1 - 6 j and then x^2-yk, yeah, it's 3.

Similarly, K1 initially claimed that s/he could not remember how to solve a problem about incompressible flow. But again, focusing on the question gave him/her the powers of concentration required to recall and mentally process the problem, leading to the recall of the right solution pathway. S/he expressed this when s/he stated, 'I think actually now that I'm looking at it, I can attempt it':

Yeah. Now, this question, do you remember it?

Um, no. I don't remember this question, I don't think.

Ok. Try it. Can you get the answer? Or if you see it, what do you need to do to be able to get, arrive at the answer?

One of them's, um, either div, grad or curl's got to be 0, but I can't remember which one.

Ok.

And then I know you work backwards from that, by going to 0 to get a...

Ok. And it's div v that's got to be equal to 0, or incompressible flow. So, if div v is equal to 0, what do you need to do? Let's say div v, yeah, it's got to be equal to 0. What do you think the answer will be?

Um, I think actually now that I'm looking at it, I can attempt it. I do remember this, but...

Try to solve it. Give yourself 60 seconds, let's say, in class. EVS, time to vote.

Um, answer number 3. 2.

Ok. Why is it 2?

Um, because the second component takes off 1y, and, so does the third. So you need to have 2y...

Yeah.

... to start with.

4.5.3 DIAGNOSTIC FUNCTION

Deliberate practice provides benefits beyond getting students to mentally engage with the lecture material by having them solve related problems. It is also beneficial because it serves a *diagnostic* purpose – that is, it shows students whether or not they understood a problem or topic as well as they thought, as both K4 and K9 questionnaire entries earlier presented demonstrate. K5 also stated elsewhere on the questionnaire that EVS use has 'helped to see where my weak and stronger areas are'. In the interview, K9 further amplified the diagnostic function that having to answer EVS questions provides to students when s/he explained that, 'It isn't until you do a question that you actually know if you can or not':

Yeah. So that's what I want to probe. This third question says that 'in what way has voting systems helped or hindered your', the learning that's taking place in the module, MAB104. And you say you, here, that it has helped you to see your where your weak and strong areas are, and it also helps you see how you are doing compared to the rest of the class.

Yes.

When you say your strong areas – first of all, what do you mean by it has helped you identify your strong and weak points?

Well, when you go through an example, or maybe C's teaching you something, I sometimes think 'oh, I get that', but it isn't until you do a question that you actually know if you can or not.

Ok.

And it helps, because we do do questions very regularly, and it makes you ident... I just feel it identifies where I need to put a bit more work into and where I don't have to put as much work into.

Similarly, K8 posited that having to answer EVS questions in lectures served as a test of ability or understanding:

What do you mean by that? Are there any particular topics that it's helped you with, that you remember from voting systems or the use of a question with voting systems? I mean, have refined your understanding of this topic or that topic? Does anything come to mind?

I can't say particularly any topic, but most of them, I would say. It does help, because when you learn something, and then to test your ability, to test if you've understood it, that's when the voting system comes in, you know?

Yeah.

She gives us a question, and then to see if we can do it, we actually start doing it and then if we have understood, if we know what it means…

4.5.4 QUESTION RE-ATTEMPT: CLOSING THE GAP

In addition, deliberate practice also gives students, based on feedback from the instructor and often, input from peers, the opportunity to redo, usually outside the lecture, the question that they had not answered correctly. Otherwise, it is possible for students to get a question wrong in class, and get the question wrong again at a future date, because they had failed to 'close the gap' in their understanding through repeat practice.

Closing the gap in this context refers to the student (knowledge) deficiency in how to solve a problem, exposed through feedback by the instructor [e.g. Nicol & Macfarlane-Dick, 2004; Black & William, 1998; etc). Ideally, the feedback should help in addressing this deficiency because students are usually provided with an explanation on how to solve a problem, and often why some of the distracters were the wrong options. However, in some cases especially for difficult or complicated questions, students actually have to re-attempt the question in order to close the gap in their understanding.

In the excerpt below, K8 explained how s/he personally found that s/he had to redo a question in order to address the gap in his/her understanding of the problem before s/he could successfully attempt a similar question in future. S/he admonished that to be able to successfully answer a similar question in future, students need to 'write it down [i.e. feedback from instructor] on paper and then solve it. Only then can you do the same question again without, without getting it wrong':

So, and, that's always solved your problem? I mean, whenever, let's say you got a question wrong, and then she provided feedback, it's always been your experience, has it always been your experience that that's all you needed? That, that means that, if you got a question wrong and she gave you your feedback, then you'd be able to solve that question again on your own. Or have there been times when, even after she gave the feedback, you still didn't understand and you had to go and do extra work?

There are times actually. If, when you get feedback on a question...

Yeah.

... you still have to actually solve it.

Yeah.

Because if you don't solve it, if you just understand, that happens with me quite frequently actually –

It won't help if you don't do it.

Yeah, exactly. If you don't do it, you're still going to get it wrong.

The next time?

Yeah.

Ok, so –

Because even if you understand everything in your head when you actually solve it, you, you just –

Because there's still, there might be one step that you cannot, didn't pay particular attention to.

Yeah. Exactly.

Ok.

You need to write it down on paper and then solve it. Only then can you do the same question again without, without getting it wrong.

4.5.5 SUMMARY

In summary, the use of EVS questions in lectures provides a means for facilitating cognitive engagement via deliberate practice. However, it seems that some students are not addressing the gaps in their understanding of relevant subject matter, as identified through EVS practice. I think that the failure to correct mistakes highlighted through deliberate practice is one reason why EVS use may have limited impact on student learning and/or achievement. For example, I observed during the interviews that some students could not answer the same questions they had found difficult in class, which suggested that they had not revised or revisited the questions. Yet learning is most effective when people engage in "deliberate practice" that includes active monitoring of one's learning experiences (Bransford et al, 2000, p59).

It might be expected that there might be some reservations about the implementation of deliberate practice in lectures. These reservations include:

1. Limited time in lectures to implement deliberate practice and the pressure to compete the course curriculum or cover module content

2. Deliberate practice is better implemented in tutorials

3. Dumbing down: instructors should not have to provide all the mental stimulation and/or learning direction for students at the university level

Implementing deliberate practice does mean that an instructor has less time to cover module material in lectures, as time has to be allocated for lectures. Now this is a valid constraint. But the real question that an instructor has to ask is: Do I have want to cover all module material, or do I want to cover as much as I could while ensuring that the topics I do cover are thoroughly covered, and I have also monitored student understanding of the topics as well? Admittedly, some lecturers would feel uncomfortable with the approach of being unable to cover 100% of the required lecture material. However, those instructors who have employed EVS in their lectures have generally been of the view that is better to cover most of the topics required in a way that ensures student understanding (e.g. King & Robinson, 2009c).

Another valid reservation is that it might be better to implement deliberate practice in tutorials. However, attendance at tutorials usually drops as a semester progresses (lecture attendance also drops but not at the same rate). Further, research carried out by a former Loughborough research student (Symmonds, 2009) indicated that students who struggled on their mathematics courses were the ones most likely to refrain from attending tutorials, although these students regularly attended lectures. Hence, it might be expected that the practice of having regular EVS-based QA sessions in lectures would help these students.

This naturally raises the issue of 'dumbing down' – that instruction is being designed to help weak students do what they should be doing on their own. I think it is important to keep the learning environment challenging for students, and hence instructors have to watch out for evidence of employing lower standards in their instructional practices. However, the reality is that there are students who do not or would not apply themselves as much they should to work outside the class. Also, the reality from observing student study habits and lifestyle choices, especially in the wake of tuition fees' introduction in the UK, is that many students either do not do much work outside of class or wait till assessment time before they commit to working on class material, due to a number of factors including part time employment (BBC, 2010).

Moreover, the goal of instruction should ideally be to reach or help as many students as possible, using a variety of practices and styles appropriate to the context

(e.g. Angelo & Cross, 1990). Therefore the design and use of questions to assess student understanding in real time in lectures is a viable educational intervention, especially as such instructional practices may also benefit the more capable and motivated students. Moreover, if the performance of weaker students improves as a result of EVS use (King & Robinson, 2009a; Boyle et al., 2001), this is an added benefit rather than a disadvantage.

Further, the EVS questions used in class are few and so the students who could be expected to gain the most benefits from EVS use are those who were and are in the habit of extending their learning and related practices beyond the walls of the classroom (see section on Closing the Gap). Thus, the real utility of EVS by default could be stated to be the stimulation of further exploration or practice to extend student understanding (Draper, 2009).

In summary, EVS use presents students with opportunities to implement instructional measures and practise problem solving skills in real time and while the material is fresh. This deliberate practice helps strengthen their cognitive processing skills and comprehension of how to solve particular problems. Further, deliberate practice serves a diagnostic function by helping students identify areas where they need to improve. In the absence of this practice, students might be lulled into a false sense of confidence about their abilities. Moreover, instructor feedback together with work outside the class might help students to address the problem areas identified through working on EVS questions. EVS is therefore a potentially significantly beneficial tool with respect to helping students accurately assess their understanding of relevant learning material.

In the next section, I will present briefly the disadvantages of using EVS, which might have a negative impact on student engagement.

4.6 DISADVANTAGES OF USING EVS

As part of the interview protocol, I asked interviewees to comment on any negative aspects or disadvantages of using EVS in lectures that they had experienced or observed. In addition, the interviewees also often commented during the course of the interviews, without my prompting, about aspects of EVS that they considered to be potentially disadvantageous. Due to volume constraints, I have provided below a

summary of these disadvantages, based on descriptions provided by interviewees and supplemented by both my classroom and interviewee observations:

- **EVS Malfunction:** these include technical i.e. EVS handset and (Turning Point) and software malfunction, and malfunction due to human error;
- **Non-Voting:** which comprise issues surrounding the logistics of distributing handsets before lectures, low student participation in some EVS QA sessions, and sufficiency of voting time;
- **Usage:** which comprise issues around the perception of some questions/distracters as being sloppy or ineffectual, guesswork, student swapping of answers, flippant attitude towards voting, and the feeling that some lectures are 'rushed' due to EVS use.

In summary, the most important disadvantage mentioned or the one that could have potentially high influence on student learning is the use of 'sloppy' questions and/or distracters. In answering one of the EVS questions posed during the interview, which had also been used in class, K2 pointed out that the distracters were too obvious, and that other options could have been used to make the question more challenging:

Well, this is where the disadvantage of the voting system comes in 'cause there's only one answer up there with 2 – y. Whereas I'm thinking, for the same example, the same question, was up there with the 2 – y on the first integral, not on the second integral, I think you might get a few more people going 'ah'.

Which one?

And making them think 'do I switch it?' But obviously for me looking at that I can say that, but that's the disadvantage to this method. Whereas if that was a little bit closer for this example, number 4, um, the first integral was 0 to 2 – y, I think you'd probably get better results between 3 and 4 for that reason.

The other disadvantages, for instance, software and hardware malfunction occur sporadically. Moreover, technical expertise and confidence with using technology usually increases with time (King & Robinson, 2009c). An aggregation of the student comments also indicated that the time allocated for voting was usually sufficient, and that EVS use for voting did not have a negative impact on lecture time, except towards the end of the semester. Further, the cases of reported flippancy towards EVS use and swapping of answers seemed to have been limited occurrences.

4.7 THE INTERCONNECTEDNESS OF EMOTIONAL, BEHAVIOURAL AND COGNITIVE ENGAGEMENT

One question that may be asked is how the different elements of engagement interact, especially as they have been presented separately in this chapter. A simple response to that question would be that emotional, behavioural and cognitive engagement are interrelated. The presence of one influences the others and vice versa. Students who are emotionally engaged – i.e. who feel connected and display positive attitudes towards learning while using terms like fun, exciting, helpful to describe the teaching approach and/or learning environment are far more likely to be behaviourally and cognitively engaged or immersed in classroom activities. This may be summarised as: Students who are fully engaged are not necessarily learning. However, students who are not engaged will not learn (Watson et al., 2003). Hence engagement is a precursor to real learning.

Further, students usually do not make distinctions between the different types of engagement. It is researchers who have to make this distinction in order to study engagement at a fine-grained level. In K8's response to a pre-interview question on how EVS had helped or hindered his/her learning in lectures, s/he did not make a distinction between the different layers of engagement. Rather, his/her response showed elements of emotional, behavioural and cognitive engagement (see italicised keywords from the excerpt below):

'The voting systems used in MAB104 helped my revision of calculus. It is a change to what usually happens in a lecture. This makes sure that most of the students in the class focus on the lecture. It has been very helpful for me so far.' [Emphases mine]

For instance, 'change' and 'very helpful for me', within the context above, are both terms relating to affect or emotional engagement. In contrast, 'focus' refers to behavioural engagement. 'Very helpful for me' could refer to either cognitive or emotional engagement, or both.

This conception of engagement as a rubric with three interwoven dimensions is in keeping with the postulation of Fredricks et al. (2004) who observed that:

'Defining and examining the components of engagement individually separates students' behaviour, emotion, and cognition. In reality these factors are dynamically interrelated within the individual; they are not isolated processes. Defining and examining the components of engagement individually

separates students' behaviour, emotion, and cognition. In reality these factors are dynamically interrelated within the individual; they are not isolated processes.'

Moreover for real learning to occur and as research literature clearly indicates (e.g. Helme & Clarke, 2001), students have to be engaged. Therefore, the position of this study is that engagement precedes learning. Watson et al. (2003) succinctly captured the relationship between engagement and learning thus:

'There is a connection between engagement and learning; students cannot learn unless they are engaged, and engagement is a combination of social, emotional, intellectual and task characteristics. Teachers had to work on all these facets to ensure engagement. All teachers believed that learners' concentration and participation could be developed.' *(p12)*

The authors of the Watson et al (2003) study also observed that 'sometimes students have to feel better before they learn more' [mathematics] (p5). To put it in another way, students who feel that the learning environment is not conducive may experience a feeling of 'alienation'. However, self-reported measures of student satisfaction and enjoyment of learning do not always translate into meaningful learning gains. For example, in the study (Crouch & Mazur, 2001), some students had complained that they did not enjoy the method of instruction adopted, and yet the students were shown to have displayed learning gains through an instructional measure they were less than satisfied with. In another study, Pashler et al. (2009) described how students who did not enjoy a class, because the instructional measure adopted was oppositional to their preferred learning style, nevertheless performed better within the less liked instructional environment than in their preferred learning environment.

In reality, the interplay between engagement, especially emotional engagement or affect, and learning is a complex one and incorporates or necessitates a detailed consideration of themes such as beliefs (e.g. teacher's, student's and self-efficacy beliefs), motivation and metacognition (See Figure 4.1 for a composite picture of this relationship).

For example, the overlap between affect and motivation (Figure 4.1) may be illustrated through the experience of K4. S/he narrated how the enthusiasm of a teacher not only helped him/her to develop positive attitudes, but also motivated him/her to perform well in mathematics at A level:

Ok, um, ok, so, yeah. So, maths was compulsory at your college?

Yeah. It was –

But you enjoyed it?

Yeah. Like, when I first got there, I was told that I didn't have the skills, like, necessary to succeed in maths by this horrible teacher. And I really, like, hated it for a while...

Yeah.

... and then I changed my teacher and he made me see that maths is, like, fun. It was awful. But, yeah, I don't know why I enjoy it. I think it was the teacher I had. He just gave me a passion for, like, maths. I don't know why, it's such a weird thing to like.

So you preferred a good teacher who opened you up to a new world...

Yeah.

... to see how a different way of teaching can –

Yeah, I think his passion for the subject kind of rubbed off on everyone in his class. It got me an A.

Socio-historical context

Classroom context

Student/teacher

Cognition

Math knowledge and strategies for learning/teaching

Metacognition

Metamotivation   Meta-emotion/affect

goals   Belief system

needs   emotion   attitude
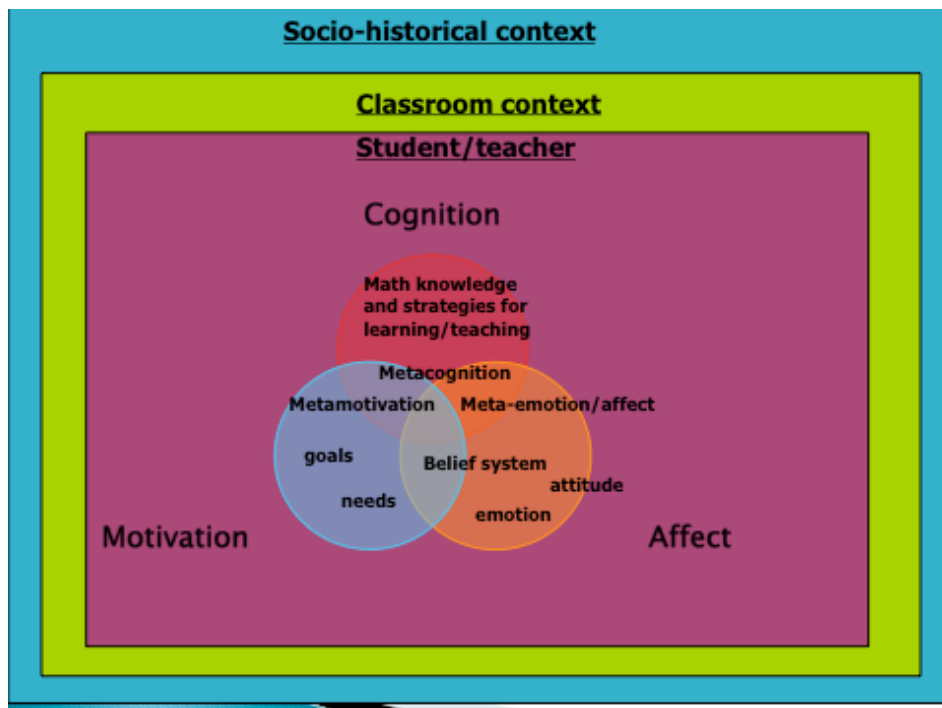
Motivation   Affect

Figure 4.1 The interplay of affect and motivation/cognition on teaching and learning (Hannula, Panziara & Waege (2009).

In addition, research in the field of engagement and mathematical thinking is considering how 'personal meaning, teachers' emotional knowledge (emotional skills) [and] humour' (Hannula, Panziara & Waege, 2009) as engagement constructs may influence mathematics teaching and learning. However, a detailed investigation of these issues is beyond the scope of this thesis, although aspects of motivation, using goal theory, will be employed in characterising student approach(es) to learning mathematics (Chapter Five).

4.8 STUDENT ENGAGEMENT AND ACHIEVEMENT

A critique of research on EVS impact on learning to date is the tendency for such research to mainly present findings on student attitudes or views of EVS usefulness (e.g. Kaleta & Joosten, 2007; Simpson & Oliver, 2007), which are only one measure of emotional engagement. Therefore, a goal of this study was to evaluate whether EVS use has had any impact on student performance, as determined by mean student grades, attendance and retention.

To do this, I compared the mean academic grades of four cohorts of students on a second-year engineering mathematics module taught by the same instructor (this is the same instructor/module combination that respondents for this study were selected from) over the 2006/7, 2007/8, 2008/9, 2009/10 academic years (see Table 4.2). It should be noted that apart from the 2006/7 cohort in which EVS was not used, the classroom experience for all the other three cohorts included regular EVS use. Also, coursework was intentionally made more demanding for the 2007/8, 2008/9 and 2009/10 cohorts. Otherwise, the three cohorts are directly comparable, as course content and assessment modes remained unchanged across the four cohorts.

The results (Table 4.2) show that EVS use does not appear to have had a positive or negative impact on student performance, as indicated by the mean overall grades of the four cohorts. Observations of lectures also indicated that EVS use did not have beneficial impact on student attendance. Further, EVS did not appear to have any positive impact on the student failure rates. It is reasonable to expect that if EVS is indeed beneficial to student learning, this should be somewhat reflected in the student academic performance. On that note, EVS comes up short. In fact, recent statistical as well as qualitative evaluations do not report any significant learning gains accruing

from EVS use (e.g. Bugeja, 2008; Johnson & Robson, 2008; Socol, 2008; Groveman, 2008).

COHORT CHARACTERISTIC	2006/7	2007/8	2008/9	2009/10
NO. OF STUDENTS	145	147	156	146
COURSEWORK AVERAGE	81.3	58.9	64.7	58.3
EXAM AVERAGE	59.2	62.0	58.4	60.4
OVERALL AVERAGE	63.2	60.3	59.7	60.0
% OF STUDENTS FAILED	13.8	14.9	7.7	16.4

Table 4.2 The academic performance of students on a second-year engineering mathematics module over a four-year period.

However, the finding that EVS appears to have no positive impact on student performance might need to be interpreted with caution. This is because the EVS questions that have been used for the engineering mathematics class investigated, and for which there is ample evidence that their use has contributed to improvement in engagement; tend to be structured into short, specific problem sets. In contrast the module examination, which accounts for 80% of the overall module grade, typically consists of longer essay-type questions. It is therefore plausible that the type of procedural fluency skills that students acquire through exposure to EVS use, especially through deliberate practice, are not being assessed within the current examination structure, which has been in place prior to the 2006/7 session.

Moreover, research evidence indicates that benefits from technological intervention in the classroom often start to appear from the second year of implementation (e.g. Somekh et al., 2007). Further, as instructor skill and confidence with using EVS in the formative teaching mode increases, this could be expected to somewhat impact student performance (e.g. Boyle, 2006; Crouch & Mazur, 2001; Boyle et al, 2001). So it is still quite plausible that EVS use might show a positive correlation with academic performance in the long term. Also, evidence from other institutions (e.g. Boyle et al 2001) indicates that regular EVS use may help improve the scores of weaker students.

Further, Biggs (1999) advocated synchronisation or alignment between teaching, learning and assessment. Future research could therefore focus on an investigation of what the results would be if the type of questions featured in the module examinations were typically what students are presented with when EVS is used in lectures. An alternative would be to feature more of the type of EVS questions that are currently being used in lectures in examinations, and then compare the results. An area for future research would be to have tutorials with EVS, and tutorials in which EVS is not used, and then devise a suitable test to compare the performance of students in the two groups, which would have a single instructor. But it is important to reiterate that the evidence from this study does not indicate an association between regular EVS use and improved academic performance.

4.9 CONCLUSION

This chapter was designed to provide insights to the research question, How has the use of EVS impacted (or otherwise) *student engagement* with respect to the learning of mathematics at university? To answer this question, I have presented evidence from interviewee transcripts about the impact that EVS use has had on how students feel, behave and think in class. For example, the fact that students are able to answer questions anonymously has an enormous impact on the numbers of students responding to questions in class. Anonymity helps remove or reduce the fear of being labelled stupid or being embarrassed in front of peers, in the event of getting a question wrong.

Further, EVS use serves as a way of initiating, maintaining or re-focussing student attention in class. The use and timing of EVS questions thus play a major role in facilitating student attention. Similarly, EVS use not only facilitates increased student participation in mathematics lectures, it also enhances the mode and frequency of interaction students have with their instructor and one another. EVS is in addition a significantly beneficial tool with respect to helping students accurately assess their understanding of relevant learning material. However, the use of sloppy questions is seen as being detrimental to the cause of student engagement. Overall, there seems to be no association between EVS use and improved (or otherwise) student academic performance, retention or attendance.

The unique contributions of this study include the fact that it describes in detail the outcomes of a specific educational intervention – EVS use – on student engagement in mathematics. The outcomes are also presented specifically in terms of the three expressions of student engagement. Further, the evidence presented is based on a qualitative research methodology i.e. semi-structured interviews, whereas studies on engagement are typically based on data from quantitative instruments.

CHAPTER FIVE

CHARACTERISING STUDENT APPROACHES TO LEARNING

5.1 INTRODUCTION

The purpose of this chapter is to answer the research question, What is the student's approach to learning mathematics? The aim is to characterise a student's approach, at the course level, to learning mathematics on the module being investigated, based on evidence from interviewee transcripts. To undertake these characterisations, I will be utilizing Marton and Saljo's (1976a), approaches to learning theory (ALT), framework. To provide alternative views of student learning approach characterisation, I will also be employing goal theory (e.g. Pintrich, Conley & Kempler, 2003), and the three worlds of mathematics framework (Tall, 2008). The goal is to characterise individual interviewees as to whether they exhibit a surface or deep approach to learning mathematics.

It should be noted that the learning approaches that students adopt at the course or module level is often different from the approaches they adopt at the task level. The distinction is that how students approach a task e.g. question or problem is not necessarily the same as the one they adopt at the whole course or module level (e.g. Case & Marshall, 2004). Hence this chapter will focus on a characterisation of student learning approaches at the course level, while Chapter Six will focus on a characterisation of student learning approaches at the task level

This chapter begins with the presentation of related literature review and rationale for the adoption of the multiple theoretical frameworks that I have employed, in primary and secondary analyses, to characterise student approaches to learning mathematics. Then I briefly introduce the strategies I used in analysing interviewee transcripts with a view to characterising individual student learning approaches – that section is predicated on the methodological procedures introduced in Chapter Three. This is followed by the data presentation and subsequent characterisations of the

approaches to learning mathematics of four selected interviewees (I could not present data for all 10 interviewees due to space constraints). These four were selected because their learning approach characterisations represent a whole spectrum of learning approaches that I would like to highlight. The chapter concludes with a discussion of the interrelationships between the different theoretical frameworks employed for characterising student learning approaches and the implications for mathematics learning.

5.1.1 CONTRIBUTIONS

This study makes contributions to the literature on student learning approaches in three ways:

- The adoption of an integrated, multiple theoretical framework for the primary analysis of data, with a view to providing a rich description and documentation of the frameworks that may be used to characterise student learning approaches
- The adoption of a mathematics-specific theoretical framework for the secondary analysis of data, with a view to investigating whether there are any qualitative differences or similarities in the characterisations produced in primary analysis;
- The adoption of interviews as the method of inquiry in order to provide context-based views of 'meaning and understanding, which are often not captured in standard inventories used in evaluating student learning approaches (Marshall & Case, 2005, p260; Haggis, 2003, p94). For example, Case and Marshall (2004) showed how a student who had earlier been characterised as displaying a surface approach, based on her submissions to an inventory, was later identified as displaying a deep approach based on 'interview evidence' (p261).

5.2 INTRODUCING THE APPROACH TO LEARNING
THEORETICAL (ALT) FRAMEWORK

In 1976, two researchers investigating how students approached a reading task described how some of the students employed a 'surface' approach, characterised by rote learning and simple memorisation, while others adopted a 'deep' approach, characterised by meaning-seeking or understanding intentions. This classification

subsequently became known as the classic deep and surface approaches to learning, or the approaches to learning (ALT) theoretical framework (Marton & Saljo 1976a,b; 1984); although other researchers notably, Skemp (1976 & 1971) i.e. theory of relational and instrumental understanding, and Biggs (1978), were also developing similar themes at about the same time.

Since Marton and Saljo's groundbreaking study, many researchers working across different institutional and geographical contexts have unearthed similar learning approaches in the student populations they studied (e.g. Entwistle & Ramsden, 1983, Ramsden, 1984, 1988, 1987, 1992; Entwistle, 1997; Biggs, 1999; Prosser & Trigwell, 1999, etc). Most of the approaches uncovered by researchers in the different disciplines were classified under the classic surface and deep categories.

It is now recognised that student approaches to learning are heavily influenced by the context, hence the approaches that students adopt in different disciplines may vary due to the often different requirements (e.g. Ramsden, 1988; Drew, Bailey & Shreeve, 2002). It is also now recognized that it is possible for students to change their learning approach in moving from one course context to another i.e. a students may adopt a surface approach in one course context and then 'switch' to a largely deep approach in another course (e.g. Meyer, 2000; Barnet, 1990; Entwistle & Ramsden, 1983, etc). Hence, student approach to learning is sometimes construed as a response to the perceived course context (e.g. Case, 2000; Case & Marshall, 2004; Hazel, Prosser & Trigwell, 2002). A distinction has also been made between the type of approach that students adopt at the task level, and that which they employ at a whole course level (e.g. Booth, 1992; Case & Marshall, 2004; Drew, Bailey & Shreeve, 2002).

In mathematics, research also suggests that there is a correlation between student perceptions of mathematics and the type of learning approach adopted. For example, Crawford et al. (1998, 1994) indicated that students who have a 'cohesive' conception of mathematics, i.e. see mathematics holistically as a template for the creation of knowledge in the form of mathematical thinking, were more likely to adopt deep learning strategies (also see Drew, 2001). In contrast, students who have a 'fragmented' conception of mathematics, i.e. see mathematics more or less as an elevation of arithmetic or a combination of formulae to use in answering questions were more likely to adopt surface approaches to learning.

The approach to learning theoretical (ALT) framework has proven useful in understanding how students approach learning situations. Hence, the framework has been voluminously utilised in describing research into student learning, its popularity

due to the potential of the framework to describe a 'recognisable reality' (Entwistle, 1997a; as cited in Marshall & Case, 2005). The downside to this proliferation of research utilizing this framework is that the proponents have often not been self-critical, or attempted to integrate other learning theories to either critique, or complement the application of the framework to their respective research undertakings (Haggis, 2003; Webb, 1997). Haggis also indicated that the ALT framework has often been presented as the 'holy grail' of student learning, while some researchers have ignored the potential shaping influence of context on learning approach.

The utilisation of the ALT framework to the data interpretation and categorisation is also approached from a largely constructivist/interpretivist perspective, as advocated by Marshall and Case (2005):

From a constructivist/interpretivist perspective, we would argue that all research findings should be considered as heuristics or 'thinking tools', rather than as representing any sort of absolute truth. In this article we have argued for studies that are more contextually nuanced, situated in a constructivist/interpretivist rather than a positivist paradigm, and drawing on other theoretical perspectives. However, we have also outlined ways of researching using approaches to learning theory that are nuanced, sensitive to context, and open to the incorporation of other theoretical perspectives, especially where these help understand the very real difficulties that learners have in adopting the deep approaches that are often required in higher education contexts. (p265)

I need to state here that I am using the ALT framework as a descriptive tool for interpreting and/or understanding how the students I interviewed approached learning situations (Burton, 2002). I consider the ALT framework a way of representing or characterising the different approaches that students may adopt towards learning. There are other frameworks that may be employed in analysing student approaches. For example, there is considerable research on how learning styles may influence student approach to learning, and how specific instructional practises that build on this knowledge of learning styles may be constructive in helping students learn better (e.g. Felder, 1996; Kolb, 1994).

Another framework for analysing student approach to learning mathematics is the conceptual change theoretical framework (e.g. see Tirosh & Tsamir, 2004) which has as its tenet the supposition that 'students' prior knowledge is often incompatible with some central mathematical notions they are to acquire', such that this prior knowledge base has to undergo radical or more marginal development or reification for the development of the desired 'central mathematical notions' (p536). Further, Fischbein's theory of intuitive knowledge (Fischbein, 1987, 1993), described as a 'type of immediate, implicit, self-evident cognition that leads in a coercive manner to

169

generalizations' (Tirosh & Tsamir, 2004, p537), is a useful framework for explaining the 'essential role [that intuitions play]…in students' mathematical and scientific thinking processes' (p537). There is also Stavy and Tirosh's (2000) theory of intuitive rules, which is based on the observation that 'students react in similar ways to a wide variety of conceptually non-related mathematical and scientific tasks that have some common, external features' (Tirosh & Tsamir, 2004, p538). This theory helps illuminate how an understanding of student presuppositions, i.e. intuitive rules about specific mathematical topics, is crucial to helping students develop a comprehensive and holistic appreciation of the relevant mathematical concepts.

5.3   APPLYING   THE   APPROACH   TO   LEARNING THEORETICAL (ALT) FRAMEWORK

5.3.1 BACKGROUND

As stated earlier, 10 interviewees participated in the study. I adopted interviews as the method of inquiry in order to provide context-based views of 'meaning and understanding, which are often not captured in standard inventories used in evaluating student learning approaches' (Marshall & Case, 2005, p260; Haggis, 2003, p94). For example, Case and Marshall (2004) showed how a student who had earlier been characterised as displaying a surface approach, based on her submissions to an inventory, was later identified as displaying a deep approach based on 'interview evidence' (p261).

Using the ALT framework and emulating research in the field, I wanted to analyse and categorise the interviewees into appropriate ALT groups. To undertake this analysis, I employed the descriptive Case and Marshall (2004) Criteria i.e. the intention/strategy model introduced in Chapter Three (see Chapter 3.3.5) provided by Case and Marshall (2004), and henceforth referred to as CAMC. The CAMC is predicated on the fact that if the intention(s) and the corresponding strategies for learning of a student are known, then it might be possible to characterise the student's learning approach, with respect to the ALT framework - the CAMC model is presented in Table 5.1. I decided to use CAMC for three reasons:

- Research on ALT is context dependent. So a study on ALT in philosophy may not necessarily be (specifically) applicable to another study in genetics. As both the CAMC study and my study are undertaken with engineering students, It makes scientific sense to apply CAMC as a diagnostic tool for my research;
- Second, the Case and Marshall study identified four different expressions of ALT (surface, procedural surface, procedural deep, conceptual deep), which are more relevant to an engineering mathematics domain, instead of the classic deep and surface model;
- The study provided descriptive criteria in a transparent and accessible manner on how they analysed their data and categorised students into various ALT groups, and this facilitates *transferability* (Lincoln & Guba, 1985, p123).

	INTENTION	
STRATEGY	Passing the test	Understanding
Memorisation	Surface approach	
Problem-solving	Procedural surface approach	Procedural deep approach
Concepts		Conceptual deep approach

Table 5.1 The CAMC criteria based on an Intention/Strategy model (Case & Marshall, 2004).

5.3.2 OTHER THEORETICAL FRAMEWORKS

In keeping with the recommendation of the Marshall and Case (2005) study for the application of other theoretical constructs in investigating student approaches, I am adopting two complementary theoretical frameworks in analysing data provided by interviewees. The first of these is classic (achievement) goal theory which, incorporated alongside the ALT framework, will be used for the primary analysis of data, with respect to characterising student approaches. The second is David Tall's three worlds of mathematics (Tall, 2008), which will be used for the secondary analysis of data.

5.3.3 GOAL THEORY

Classic goal theory describes student approach to learning as arising from either a mastery or performance *goal* orientation (e.g. Printrich, Conley & Kempler, 2003; Fredricks, Blumenfeld & Paris, 2004; Pintrich 2000a, b, c; Wolters, Yu & Pintrich, 1996; Pintrich & Schunk, 2002). Deemer and Hanich (2005) describe students with a mastery orientation thus: 'Students who adopt mastery goals approach learning situations with a focus on understanding material, not simply reaching an outcome, as students with performance goals do in learning situations'. In other words, 'mastery goals reflect a focus on developing competence, learning and understanding the task' [while] 'Performance goals reflect an orientation to demonstrating competence…'. Hence those students with mastery goal orientations are focused on *developing* competence, while those with performance goal orientations are fixated on *demonstrating* competence.

Further, performance or mastery goal orientations 'represent the individual's "orientation" to the [learning] task or situation, their general focus or purpose for achievement, and not just the specific target goal they have for the task' (Pintrich, Conley & Kempler, 2003). Mastery and performance goal orientations are therefore demonstrably analogous to the deep or surface approaches to learning, a link that has been demonstrated in previous research. For instance, in Pintrich, Conley & Kempler (2003), the authors stated that 'students who endorse mastery goals are more likely to use deep-level strategies such as elaboration or organisation', whereas performance oriented students are 'less likely to utilise deep-processing strategies', and thus more likely to adopt surface-level strategies (also see Weinstein & Mayer, 1986; Ames & Archer, 1988; Miller et al, 1996; Pintrich & De Groot, 1990).

To use goal theory to characterise the learning approaches adopted by interviewees, I have employed the use of the intention/strategy interface earlier described in Section 5.3.1. Intention refers to the goal orientation of the interviewee, while strategy refers to the study methods s/he adopted to realize that goal (see Table 5.2). Moreover, both goal orientations and the ALT framework share the distinction that the orientations/approaches that they describe are malleable - unlike learning styles, 'approaches to learning are not characteristic of learners' (Marshall & Case, 2005, p259) i.e. they are subject to change and are context-dependent.

CLASSIC GOAL THEORY	INTENTION FOR LEARNING Intention: Why they do it	STRATEGY FOR LEARNING Strategy: What students do
PERFORMANCE	To *demonstrate* competence by meeting or surpassing the relevant assessment standards	Characterised by a focus on rehearsal strategies
MASTERY	To *develop* competence or mastery of course material	Characterised by a focus on elaboration or comprehension monitoring strategies

Table 5.2 A simplified explanation of classic goal theory based on an intention/strategy model.

Distinguishing between Procedural Deep and Conceptual Deep Approaches

Using the Case and Marshall (2004) study or classic descriptions or characterisations of the ALT framework in literature for that matter, it is often difficult to differentiate between Procedural Deep (PD) and Conceptual Deep (CD) approaches. This is especially so due to the problem solving nature of the mathematics module being investigated, which necessitates a focus on the use of procedures. In this context therefore, students from both the PD and CD groups might be expected to rely on the use of procedures in solving problems.

So I turned to classic goal theory, and the characterisation of the strategies employed by students as being either elaboration or rehearsal-focused (Pintrich, Conley & Kempler, 2003; Fredricks, Blumenfeld & Paris, 2004). Although both PD and CD in the engineering mathematics context contain the elements of both elaboration and rehearsal, there is a greater concentration of elaboration strategies in CD. In addition, owing to Case and Marshall (2004), a distinction may also be made about the timing of the intention to understand. Students with the CD approach have a stated preference for *concurrent understanding* i.e. they try to understand the underlying concepts at the time of attempting the task, and not at a later date. Students displaying a PD approach on the other hand exhibit a preference for *subsequent understanding* i.e. they do not necessarily want to understand or relate the underlying concept to the task at hand at the

time of first attempting the task, as understanding is seen as something that is achieved later through working through problems and repeating procedures (Table 5.3). Case and Marshall (2004) described this as 'students using a procedural deep approach indicated that, although this approach did not centrally focus on understanding, their expectation was that in the long run they would gain understanding through practising problems' (p610).

Approach	Intention	Strategy	Goal
Procedural Deep	Subsequent Understanding	Rehearsal strategies predominate (although elaboration strategies are also present)	Performance
Conceptual Deep	Concurrent Understanding	Elaboration strategies predominate (although rehearsal strategies are also present)	Mastery

Table 5.3 Criteria for distinguishing between procedural deep and conceptual deep learning approaches.

However, there are a couple of viewpoints in goal theory, which are not emphasised, in the ALT framework. An example is the fact that goal theory is largely focused on motivation. In classic goal theory for example, students with a mastery orientation are presented as being intrinsically motivated, while those with a performance orientation are extrinsically motivated. Those students with a mastery orientation are thought to be less responsive to context, compared to their extrinsically motivated peers. However, this has been modified somewhat by recent research, which suggests that even students who are oriented towards mastery development might use performance on assessment as a yardstick to measure their mastery (Pintrich, Conley & Kempler, 2003).

Student approach within goal theory could also be classified from either a reason i.e. 'students' reasons for engaging in achievement-related behaviours' or standard perspective i.e. 'standards individuals used to judge success' (Pintrich, Conley & Kempler, 2003). In addition, goal theory is also associated with theories about intelligence. For instance, students with a mastery orientation are described as subscribing to an incremental theory (Dweck, 2000) of intelligence, and are thus more likely to hold adaptive beliefs about learning and also display metacognitive skills.

5.3.4 STRATEGIC APPROACH

There is another approach, the *Strategic* learning approach construct (see Table 5.4 for its characteristics) within the ALT framework, that is distinct from either the surface or deep construct, due to its explicit focus on how assessment influences student approach (Ramsden, 1984), although this is not universally accepted (e.g. Volet & Chalmers, 1992).

APPROACH	INTENTION	STRATEGY
Strategic	To 'pass' exam; where pass may indicate a variety of options, ranging from mere passing the course to getting a very good grade	Mainly rehearsal strategies (including presence of Examination Intelligence, EI)

Table 5.4 Characterisation of a strategic approach to learning.

Categorising the Strategic Approach

It has been argued (e.g. Volet & Chalmers, 1992) that the strategic approach could be classified under the existing ALT characterisations i.e. surface, procedural surface, or procedural deep, as the approach does not necessarily include an orientation for deep understanding. But the work of Ramsden (1984) and others have shown that the strategic approach framework has attributes that could be argued are distinctly different from the classic surface and deep approaches. Further evidence in support of this position includes:

1. The exposition from proponents of multiple goal theory that there is evidence that in some instances both students with mastery and performance orientations exhibit a strategic approach to learning in response to the perceived context of a particular course or module;

2. Students develop what I refer to as *Examination Intelligence* (EI) as a result of exposure to formal education over the years. EI refers to the ability of students to infer from cues from the learning environment about which aspects of the module to focus on in order to maximise performance in assessments (e.g. Snyder, 1971). One factor that has contributed to this is the prevalence of a teaching-to-pass culture at pre-university level. This fixation on passing at the

expense of course content mastery or understanding is further exacerbated by the preponderance of, and significance attached to league tables;

3. In the course of the interviews I conducted (as would be shown later), students who displayed procedural deep and conceptual deep both showed an appreciation of, and adoption of, the strategic approach. The students generally showed an acute awareness of the role and importance of assessments and the need to do well on them.

The strategic approach category could be said to be analogous to the performance category in goal theory, and it may be argued that it may suffice to leave out the strategic approach categorisation. The problem with this approach is that some of the students who adopted a strategic approach would fall into the mastery camp, while some clearly belong in the performance camp.

Strategic Approach Implications for Academic Performance

It would be interesting to see whether there would be a difference in the assessment scores obtained by a student who adopts a procedural surface approach, and the scores of another student who adopts a procedural surface approach together with a strategic orientation. My hypothesis would be that the student with a strategic approach would, on average, obtain a higher score on similar assessment measures. Perhaps this is an area for future study.

In the next section meanwhile, I will present an integrated or expanded ALT framework, drawing upon constructs from goal theory and supplemented by insights from the strategic approach construct.

5.4 INTEGRATING THE ALT AND GOAL THEORY FRAMEWORKS

Based on ideas and information from ALT literature, especially the intention/strategy model, as well as goal theory, I have developed a more comprehensive framework, building upon the Case and Marshall (2004) study, with which to analyse interviewee approaches to learning from an integrated ALT perspective. Using this expanded framework I developed (Table 5.5), an interviewee whose learning intention is to reproduce material without any intention to understand such material, and who relies mainly on rehearsal strategies, would, for example, be characterised as displaying a

APPROACH TO LEARNING MATHS	INTENTION (FOR LEARNING)	STRATEGY (FOR LEARNING)
SURFACE **(Performance goal)**	Reproduction or performance orientation *without* intention to understand	Rehearsal strategies – chiefly (surface) memorization of information or rote-learning, devoid of practise or problem solving
PROCEDURAL SURFACE **(Performance goal)**	Reproduction or performance orientation *without* intention to understand	Rehearsal strategies – chiefly problem solving
PROCEDURAL DEEP **(Performance goal)**	Reproduction or performance orientation *with* intention to understand; Focus on *subsequent understanding* (i.e. implicit meaning or understanding orientation)	Rehearsal strategies predominate (although both rehearsal and elaboration strategies are present)
CONCEPTUAL DEEP **(Mastery goal)**	Mastery, meaning or understanding orientation, with focus on *concurrent understanding*	Elaboration strategies predominate (although both rehearsal and elaboration strategies are present)
STRATEGIC APPROACH	Perform well on relevant assessment measure	Examination Intelligence (EI), review of past examination papers, rehearsal strategies
Rehearsal strategies are characterised by: Identifying and memorising calculation methods for solving problems; Learning by repetition and memorisation of formulae and simple algorithms; To be able to repeat formulae and use algorithms in tests/examinations, effort-avoidant strategies that maximize short term retention of information….		
Elaboration strategies are characterised by: Relating of formulae to each other, or parts of algorithms to other parts; Working through problems and consulting textbook, puzzling over gaps in understanding; Relating of learning tasks to their underlying concepts or theory i.e. relating new information to existing knowledge, comprehension monitoring, organisation, regulating attention, persistence….		

Table 5.5 A comprehensive and expanded guide showing the criteria employed in characterising

student approaches via the ALT framework (Case & Marshall, 2004; Pintrich, Conley & Kempler,

2003).

procedural surface approach to learning. The goal theory equivalent is performance. The adoption of a strategic approach is indicated by the presence of EI and review of past papers. This integrated ALT framework, as presented in Table 5.5, will be applied to guide the characterisation of Interviewee learning approaches. But first, I will present the procedures observed for the primary analysis of data, with respect to characterising interviewee learning approaches.

The ALT framework, drawing upon constructs from goal theory and supplemented by the strategic approach construct, will be used for the primary analysis of data (see Section 5.4). The three worlds of mathematics theory (Tall, 2008; personal communication, January 22, 2010; in press), which I will be employing for the secondary analysis of data, will be presented in the next section.

5.5   THE   THREE   WORLDS   OF   MATHEMATICS' THEORETICAL FRAMEWORK

Tall (2008) presents the learning of mathematics from a three-world perspective, comprising the Conceptual-Embodied, Proceptual-Symbolic and Axiomatic Formal worlds (Figure 5.1). These three worlds are expressed as depending or building upon the innate mental or cognitive structures, Recognition, Repetition and Language, which Tall referred to as 'set-befores'. The relationship between the three worlds and the set-befores is described by Gray and Tall (1994), as quoted in Tall (2008, p7) as:

'...Recognition and categorisation of figures and shapes underpins thought experiments with geometry and graphs, while the repetition of sequences of actions symbolised as thinkable concepts leads to arithmetic and algebra. Each of these constructional processes develop further through the use of language to describe, define and deduce relationships, until, at the highest level, set-theoretic language is used as a basis for formal mathematical theory.'

The 'Three Worlds' theoretical framework is hierarchical: the ability to operate in the Conceptual-Embodied (i.e. Embodiment), Proceptual-Symbolic i.e. (Symbolism) worlds precede and/or lead to fluency in the Axiomatic Formal (i.e. Formalism) world with the acquisition of appropriate language skills to aid mathematical thinking in the latter (Tall, 2008):

School mathematics builds from embodiment of physical conceptions and actions: playing with shapes, putting them in collections, pointing and counting, sharing, measuring. Once these operations are practiced and become routine, they can be symbolised as numbers and used dually as operations or as mental entities on which the operations can be performed. As the focus of attention switched from embodiment to the manipulation of symbols, mathematical thinking switches from the embodied to the (proceptual) symbolic world. Throughout school mathematics, embodiment gives specific meanings in varied contexts while symbolism in arithmetic and algebra offers a mental world of computational power. The later transition to the formal axiomatic world builds on these experiences of embodiment and symbolism to formulate formal definitions and to prove theorems using mathematical proof. The written formal proof is the final stage of mathematical thinking; it builds on experiences of what theorems might be worth proving and how the proof might be carried out, often building implicitly on embodied and symbolic experience. *(p9)*
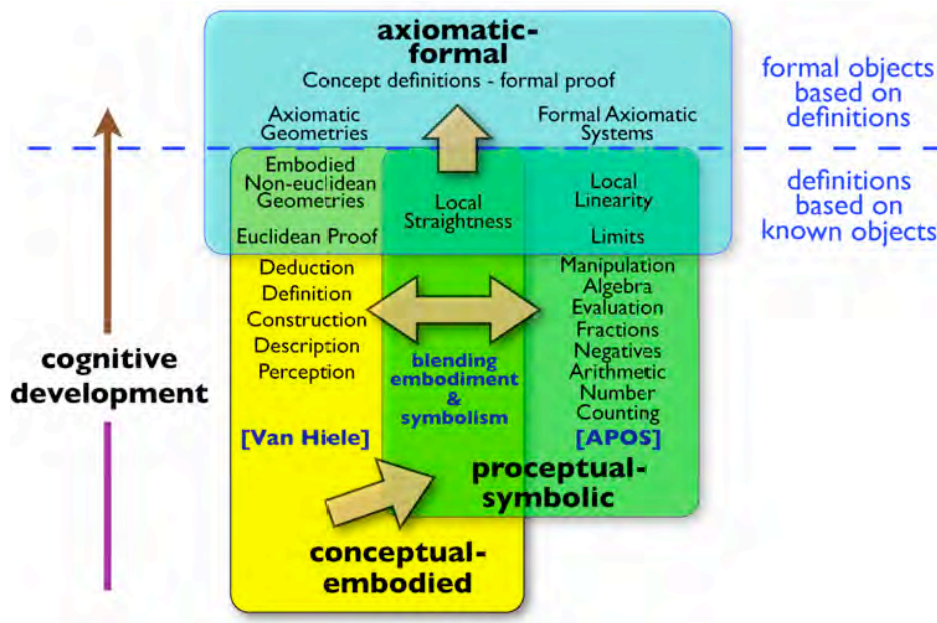
Figure 5.1 A diagrammatic representation of the three worlds of mathematics' theoretical framework[25].

So the three worlds' theory provides a means for examining the cognitive development pathway through which equivalent mathematical procedures may be conceived as a process, and which may (or may not) then be encapsulated as an object. Further, the three worlds are not only hierarchical, they are also iterative, such that attainment of axiomatic-formal fluency in turn positively impacts fluency in the performance of procedures (symbolism) and manipulation of shapes (embodiment). In addition, the proceptual-symbolic world may be singularly viewed as an instance of a group of mathematical frameworks known as process-object theories (e.g. APOS theory

---

[25] Diagram from Tall, 2008. Used with permission.

– see, for example, Asiala et al., 1996; Breindenbach, 1992).

Tall also described how 'met-befores' - 'a current mental facility based on specific prior experiences of the individual' could influence and shape mathematical thinking both positively and negatively. For instance, pupils who were introduced, at elementary school, to the notions that 'addition and multiplication give a bigger result' and/or 'take away [i.e. subtraction] gives less', which are true for natural numbers but not for integers or rationals would struggle at higher levels with mathematical problems involving negative numbers and/or fractions. This conceptual struggle could be perceived as a 'challenge' by the more confident student, while it could lead to 'anxiety' in the less confident students. In this case, Tall posited that the met-before could 'cause internal confusion that impedes learning' (Tall, 2008).

For the purposes of this study, I am mainly interested in how the blending of the embodiment and symbolism worlds i.e. embodied symbolism (Tall, in press; personal communication, January 22, 2010) may be applied in evaluating student understanding. As part of this secondary analysis, which will be presented in Section 5.10, I will also explore the influence of met-befores on the type of learning approaches that students adopt.

5.6 FRAMEWORK FOR PRIMARY ANALYSIS OF INTERVIEW DATA

In Chapter Three, I presented an overview of the analytical framework (see Table 3.4) I employed in characterising student approaches to learning mathematics. Figure 5.2 shows the template created for interviewee, K9. Some of the macro themes (see Section 3.3.3 for how macro themes were derived) are 'Intention i.e. Goals for Learning', 'Strategy for Learning' and 'Strategic approach/concentrated on mechanics', 'EVS help/study habits', etc. The numbers at the end of each macro theme refer to the page number in the interviewee transcript where the theme may be found. I will be referring to some of these themes in the next section, where I will be presenting the process I observed for characterising interviewing approaches.

Analysis Template – K9 (Jan 21, 2009) – MAB 104
Review answers to questionnaire

Conception of Proficiency – 'Good', goal – 2:2 (55%)
Found it hard [1] but enjoys it [3] [4]
Motivated to work hard at it cos s/he enjoys it [3]
So enjoys subject but does not think it's easy
But bcos s/he enjoys subject, it's easier s/he's motivated to work hard at it
Finds engr modules harder than maths
But then engr modules depends on knowl/appl of maths [4]

B at A level
40% in 1ˢᵗ year (cos s/he was concentrating on other exams)

Conception of Maths [qstnr]
'good'
Was looking forward to studying applied maths at uni, having done well at Mechanics at A level, however was shocked to find much pure maths in course: matrices, integrations, vectors [4], which s/he wasn't good at in school [4]
So 'daunting'

Goals
55% or above as to leave masters option open (extrinsic)
Done a few of the topics b4 at Indian A level, so claims
Already has 'a real understanding of the content'

Sets realistic goal [8] – about avg of performance of 1ˢᵗ year grades
Extrinsic factor – masters [8]
55% cut off point for masters

Strategy
'more practice'
Reading thru notes
Small tests i.e. evs questions [9]
Practise questions to – identify weak spots

In the past, I've revised just by reading my notes
So now practice questions to know:
Whether s/he understands topic
Identify where s/he's making mistakes

Teaching | Lecture
Easier to revise module due to clear structure and order cf sections in workbooks

Teaching | Lecture [14]
Structured approach helps
e.g. two tests – four workbooks – the 1ˢᵗ two books for the 1ˢᵗ test
Topic by section
Practice papers

So when you are stuck you know which section to go to [14]
In contrast to mechanics class 100 pages unstructured [14-15]

EVS | Benefits
'Helped'
Monitor performance
Going thru it there and then (Delib Prac)
Very helpful for him/her (affect)

Strategic Approach |Concentrated on mechanics [4-5]
To bring grade up at A level to get into uni
Hence avoided pure maths

EvS help|Study Habits [5]
Used to be via reading notes
But Evs use helped him/her track performance

EvS | Formatve purp|Anonymity [5]
Not strict test, so didn't feel bad if ans wrong cos no one else knew
Contrasted with tests where u don't get feedback until weeks later

Peer Discussion|Carol Encouraging it [6]
C encourages it
Group dynamics – sitting with friends, knowing you won't be open to ridicule, esp if u know class is strong [7]

Approach to Maths |working alone or group [7]
Prefers doing own first within a group otherwise s/he may just do all the work or copy down what peers did, esp as peers are more able than him/her, acc to him/her

Figure 5.2 The analysis template consisting of the individual-specific macro themes identified from interviewing K9.

To evaluate individual interviewees' approaches to learning i.e. identify whether a student largely displays a surface, procedural surface, procedural deep or conceptual deep approach, the following six characterisation processes or stages were adopted. In the first stage, I reviewed interviewee responses to Q4 (Table 5.5b – see below) to determine whether an interviewee specifically stipulated an intention for understanding as part of his/her goal(s) for the module. In the second stage, I reviewed interview responses to Q4 by asking them to clarify what their submissions means with respect to conceptual understanding ('Intention for Learning' in Table 5.5). The first two stages are a way of establishing the presence or absence of intention for understanding. The reason I still employed the second stage, even after an interviewee had clearly stated an intention to understand in response to Q4, was that I wanted to be verify that the interviewee did indeed have that intention, and was not merely responding in a way that s/he might have thought was the appropriate or expected way to respond.

1. How proficient would you say you are in mathematics? Please circle one.   Very good   Good   Average   Poor   Very poor
2. Before obtaining admission to Loughborough, Would you say you were looking forward to studying mathematics at university level? Please elaborate on your answer.
3. In what way(s) has the use of voting systems in MAB104 hindered or helped your learning/revision of Calculus?
4. What is your goal(s) for the MAB104 module e.g. Get a pass grade; Get a 100% score; Get a real understanding of course content; etc
5. What do you think you need to know or do to achieve your goal(s)?
6. Would you say the way or the rate you are learning in the MAB104 module is similar or different to the way or the rate you are learning in your other modules? Why is this so (Please explain)?

Table 5.5b The Pre-Interview Questionnaire containing the first set of questions presented to interviewees. Reproduced here for easier comparison.

In the third stage of analysis, I reviewed interviewee responses to Q5 (Table 5.5.b) to identify any learning strategies that they might have specified as the means by which they achieved the learning goals submitted in response to Q4. In the fourth stage, I reviewed interview submissions for Q5 by asking them to clarify, where appropriate, how they employed those learning strategies.

Figure 5.3 A sample of how I coded data to identify learning (i.e. elaboration or rehearsal) strategies.

In the fifth stage, I reviewed interviewee responses and approaches to solving the six EVS mathematics questions that I posed during the interviews (Section 3.4.2 and Figures 3.2-3.8). My interest in interviewees' approaches to solving these questions was limited to a broad, overall picture or as Case & Marshall (2004) put it, I 'focused on [student] approaches to a course in general, even though … [I] drew in part on students' task-level learning approaches'. This was because I was going to use the same EVS questions to infer the level of influence that EVS question types has on the learning approach adopted towards solving a problem. Student attempts at answering the questions enabled me to annotate and identify data sections that provided insights into student approaches.

In the sixth stage of analysis, I looked for clues to individual interviewee study habits and learning strategies as revealed during the course of the interviews, often in response to, for example, a direct question about how they prepare for examinations, what they do after getting questions wrong in class, etc. These data segments about study habits and learning strategies (see 'Evidence for CA, but starts out with PA', 'Strategy [flip comment]', and Study habits/revising for exam' in Figure 5.3) also provided me with insights into determining the presence or absence of a strategic approach. In addition, some of the data I coded on strategy/study habits, helped me in

differentiating between an interviewee with an intention for concurrent understanding, and another whose goal was subsequent understanding.

How did I make use of these characterisation processes? First, if from both first and second stages, it is clear that the interviewee displays an intention for understanding, this indicates that the interviewee's learning approach may probably be classified as either procedural deep or conceptual deep (Table 5.5). The absence of this intention is correspondingly an indication that the interviewee probably displays a procedural surface approach to learning. Examination of specific interviewee learning strategies and study habits, based on the process outlined in stages three to six above, would reveal whether these strategies are characterised by rehearsal practices (Table 5.5), which indicate a procedural deep approach, or elaboration practices, which indicate a conceptual deep approach. Review of the strategies would also reveal the presence or absence of a strategic approach.

However, a characterisation of an interviewee's approach to learning is only made by combining all the evidence from the six stages. This is the primary analysis of data with respect to characterising student approach to learning mathematics. Therefore in the primary analysis, only the ALT, goal theory and strategic approach frameworks were employed (note that goal theory constructs, such as the rehearsal/elaboration strategy construct, have been subsumed into the ALT framework. This is why there is no separate data evaluation/analysis for goal theory). Later in the chapter, I will present how the TTW framework was utilised for the secondary analysis of data.

Meanwhile, in the next section, I will present my characterisations of the approaches to learning displayed by Interviewees, K9, K2, K1 and K5, using the integrated ALT (i.e. intention/strategy CAMC model), strategic, and goal theory framework (Table 5.5). I am presenting characterisations for only four interviewees due to volume constraints. As I earlier stated, these four were selected because their learning approach characterisations are representative of the three possible ALT characterisations i.e. procedural surface, procedural deep and conceptual deep learning approaches.

5.7 INDIVIDUAL LEARNING APPROACH – K9

5.7.1 INTENTION CRITERION

On the questionnaire, K9 listed his/her intention or goal for learning on the module as:

'Get 55% or above to allow me to choose whether to do a masters or not'.

During the interview, K9 stated that s/he specified the goal above because it appeared realistic when measured by his/her previous performance. S/he also specifically set the 55% goal because that would give him/her the option of doing a masters degree, as a student could not do a masters degree without obtaining an overall course grade classification of at least 55%:

Ok. Number four here, the question I said, I asked what your goals are for the module. And you said 'to get 55% or above to allow you to choose whether to do a masters or not'.

Yeah. I think that's quite important for me this year. Um, even if I decide not to choose to do a masters, it's, it would be nice to have the option.

Yeah.

Um, so, I mean, last year didn't count. So a lot of it, I didn't revise as much as I could, because I knew it didn't help.

Yeah.

[As an aside, K9's comment here – K4 also commented about this, but K4's views are not captured in this chapter due to space constraints - seems to indicate that the Loughborough University principle that the first year results of all students do not count towards the final degree might need to be reviewed. This is because this principle often gave some students a false sense of security, such that they felt they did not have to work hard in the first year. The pitfall is that although the results of the first year do not count, the material introduced in the second year, especially in highly numerate disciples, like mathematics and engineering, often depends on instruction in the first year. So those students who displayed a lackadaisical approach or 'partied' through the first year might find themselves at a major disadvantage in their second year.]

But this year, I'd, I'd like to think that I could, that's an ambitious target in that it would make a difference but it's not so high that it's completely out of range.

Ok. Let's leave that, because it's not really part of... I just wanted to see if that ties into what you've said here. Now, 55% - what kind of grade is that in terms of class distinction, class classification?

Um...

A second class or...?

That would be a 2:2

A 2:2. And, um, the next question for this, um, on this one follows on to this question. Maybe before I ask that one – 55% is a realistic goal. And I'm not saying whether it's good or it's bad, I just want to explore more, why 55%? Why didn't you set for instance 65%? Why do you think, why didn't you set a 65% goal?

Um, I think some of my, looking at my results last year, some of them, I got 60, 70%, but some of them I got closer to 40...

Yeah.

... so an average of 55 is pretty realistic.

Right.

But also, that, that is the cut-off point for a masters, so you know, anything I get above that would be really, really great.

Yeah.

But 55% is what I'm aiming for.

Ok.

Because that's what I'd like to get.

Based on the excerpts above, however, there is no indication that K9 has any intention for mastering or developing conceptual understanding of learning material. In the next section, I would examine K9's strategies to determine whether they are characterised by elaboration or rehearsal, as well as identify any (or otherwise) references to conceptual understanding of material.

5.7.2 STRATEGY CRITERION

To achieve his/her goals, K9 stated on the pre-interview questionnaire that his/her strategy would consist of:

'More practice! Not just reading through notes but more small tests and practice questions so I know exactly what I need to work on'

In the interview, K9 explained that s/he emphasised practice because his/her previous strategy had been to focus on reading i.e. reading through his/her notes. His/her comments (see below) indicated that the reading strategy was ineffectual for learning mathematics, as s/he could not tell whether s/he was learning anything from the reading activity. His/her current focus on practice indicates a procedural deep approach as the goal is subsequent understanding ('…if I do practice questions…I'll find out..whether I understand the topic completely…'). Hence procedural fluency or ability to solve problems is expected to come through (repeated) practice:

Ok. That's good. Now, I asked, the next question says, what do you think you need to know to achieve your goals, I'm ask, I'm basically asking about strategies to achieving your goals. And you say here 'more practice'.

[Laughs] Yeah.

And, what do you mean by 'more practice'?

Um, a lot of the time in the past, I've revised just by reading my notes, and I thought that was revision. But it turns out, it doesn't really help me because I'm a slow reader, I don't read much and I've got no idea whether I'm just reading it or whether I'm learning it.

Yeah.

Whereas if I do practice questions, lots and lots and lots, even if it's the same practice question again...

Yeah.

... then I'll find out, you know, a) whether I understand the topic completely...

Mm.

... or if not, I know where I'm making a mistake every single time. So I know what I can improve on.

Ok.

So, more it's practice as opposed to more reading, really.

5.7.3 EVIDENCE FOR PROCEDURAL DEEP APPROACH

When I asked K9 to elaborate on his/her strategies, s/he indicated that although his/her approach is rehearsal-focused, the intention is to attain understanding at some point in the future by repeatedly doing suitable questions. In the excerpt below, K9 talks about

how by doing problems involving calculations with Fourier series coefficients, understanding of the underlying concepts may be achieved:

This, like I said before, there are no right or wrong answers. And I'm not leading you. I mean, I don't want you to, presuppose or assume that I'm saying that 'this is the right way' or 'this is the wrong way'. There are different approaches for people, but we're going for the same goals. So I want to say, you have this goal of getting 55%, and you want to do well, and you say have practice questions, more practice, instead of just reading, more small tests and practice questions. I just want to know, when you're doing those practice questions, what's your goal? How do you, how do you, how are you motivated to learn and what are the strategies you adopt? So that's what I'm...

Mm.

... querying and probing. Yeah. Different... I'm going somewhere with that for my own research, with what I wanted to say. So, yeah.

I think also, sometimes though as well, if you do enough practice questions...

Yeah.

... I mean, say you're finding, I don't know, some kind of Fourier series, and you wanted to find A0...

Yeah.

... and it's in the formula, but you don't really understand why it's in there...

Yeah.

... if you do it enough times, and then you'll remember that it's there and then you'll find another piece of information somewhere else and you're like 'oh, well, I worked out this from that'. But it makes sense why that piece of information's in the formula or why you have to use that formula first.

Yeah.

So, I think, you know, even, I try to understand the formula and why I'm using it before I use it. But even if I don't practice it enough times, sometimes it becomes obvious, so...

K9's comments therefore (see the transcript below) indicate that although s/he often starts with a largely surface or procedural approach, this may culminate in the attainment of conceptual understanding. This is an example of an intention for subsequent understanding or the goal of a student towards attaining conceptual understanding by repeat practice. As K9 put it, 'if you do enough questions, then it becomes obvious why you are doing it in that order'.

However, it is important to note that s/he sometimes adopts a purely procedural surface approach, which may not culminate in understanding. K9 explained that this happens 'if it just goes straight over my head, I'll just learn the steps, I'll just learn the pattern'. Further, s/he provides evidence that s/he had sometimes adopted a procedural surface approach with some of his/her engineering modules, although s/he stated s/he could not afford to do this with mathematics because the subject was often the bedrock for applied understanding in his/her engineering modules.

And if you know when to apply the formula, you can always apply it and solve your problem and get your grade. Right? Um, but sometimes, um, you might not understand what, actually, the equation of a straight line might say, for instance, plug the graph or show it in another way or see the distance between two points or two coordinates and see that and gradient, given this graph, calculate the gradient, tell us what's happening. To do that, you will need a formula. You actually need to understand how the different values of the gradient and the intersect affect what's happening to that straight line.

Yeah.

That's one way to look at it. Another way is just to remember the formula and know when to apply the formula and solve your problem. At the end of the day, both people are happy because the aim in mathematics, in a way, isn't it to solve problems? But I just want to know your goal, when you're doing mathematics problems, mathematical problems. Do you, at this point are you comfortable with just, I mean, not just, with knowing the formula, knowing when to apply it and looking at the practice questions and seeing when and how it's applied so you know what to do when you see similar questions in future?

Um, because maths, or this maths, is really useful for pretty much all of my other modules...

Yeah.

... I find it a lot easier if I understand why I'm doing it because it helps me remember normally which formula... If I know what I've got to do next and why I've got to do it...

Yeah.

... then I know which formula to use rather than just learning them in order. Um, and when I'm applying it later on, it helps if I understand it rather than just learning it. Um, so maths, I think, normally I try to understand it...

Mm hm.

... whereas in other subjects, if I just, if it just goes straight over my head, I'll just learn the steps, I'll just learn the pattern.

Yeah.

But sometimes if you learn a pattern and do enough questions...

Yeah.

... then it almost becomes obvious why you're doing it in that order.

Yeah. So that's, that's mainly the strategy you've adopted in most cases.

Yeah.

5.7.4 INFLUENCE OF TIME AND PROFICIENCY ON APPROACH ADOPTED

Although K9 has an intention to understand, if s/he is having trouble understanding and time is running out, s/he would merely adopt a procedural surface approach e.g. apply the requisite formula. S/he however stressed again that in mathematics, it is important to understand.

Yeah. I think that's great. I agree with that. What about if you're trying to understand a subject or a topic, but you're having a problem with it? But applying the formula seems to help, even though you don't understand what's happening in the formula. But you know if you say, if you see this question, all you need to do is apply the formula and you'll get it. Even if you don't really understand. If you will try to get it, the exact time is here, and you have other things to do, what do you do?

Apply the formula.

Apply the formula. So that happens in a lot of cases?

Yeah.

S/he also seemed to indicate that it was not always feasible to attain conceptual understanding at the initial stage of learning to work on a problem or applying a formula. Using an example from a fluids topic on one of the engineering modules, s/he explained that s/he initially did not understand the underlying concept but learnt how to use the formula. Nevertheless, s/he subsequently came to appreciate the conceptual framework behind the formula and could relate its use to other areas of the module:

Yeah. In your other modules, engineering modules, what's the, I, do you have to, is it something that's more that you have to understand? Or you can just know what you're expected to do and just fill in the gap? Do you understand? With about the other modules you've done in the second year?

Um, I think with maths, it's really important that you understand it.

Yeah.

With the others, if you understand it, you're going to get a lot further, but you can pass just by learning what formula you need.

Give me an example.

Um...

Any subject.

In fluids last year, um...

Yeah.

... there was some formula about, um, it was just about density and altitude and that sort of thing.

Yeah.

And it took me ages to understand it, and I didn't understand it at all. But then once I'd practised that, I could do the formula, I knew the formula off by heart, so I knew when to use it, what numbers to put in it...

Yeah.

... and then I realised that that linked quite a lot to some later questions that were using slightly different a formula but with the same principles and the same letters obviously meant the same thing...

Yeah.

... and same symbols. And because I then understood, you know, because even though I hadn't originally understood that first question, now that I understood it or knew the formula or knew what I had to do with it, it made the other bits make sense.

Proficiency and time may be viewed as complementary factors in achieving conceptual understanding. To master a concept requires diligence, a certain level of proficiency, *and* time. Moreover, observations of students working on problems indicate that all students do not operate at the same proficiency levels. Given a number of students who have a goal of mastering specific learning material, it could be reasonably expected that some of the students would require more time than the others. In the above extract for example, K9 admitted that a particular concept in fluids took 'ages to understand'. In an extract presented earlier, s/he stated that s/he often adopted a procedural surface approach when the ability to grasp the concept underpinning a subject eluded him/her: '…if it just goes straight over my head, I'll just learn the steps. I'll just learn the pattern'. So the net effect of time and proficiency often is that K9 achieves *subsequent* (conceptual) understanding of learning material through an initial focus on reproduction or rehearsal strategies.

5.7.5 LIMITATION OF INTENTION FOR SUBSEQUENT UNDERSTANDING

Therefore, as K9's intention is for subsequent rather than concurrent understanding, s/he quintessentially employs strategies that are heavily biased towards rehearsal practises. For instance, s/he explains that when given three similar EVS questions to answer in class, his/her strategy is to identify the patterns or steps required to solve the problems, and s/he achieves this by practising answering the questions alongside the feedback from the instructor:

So, more it's practice as opposed to more reading, really.

More practice as opposed to more... And you talk about more small test and I know the practice questions, I understand that, the more small, it says small test, what do you mean by that?

Um, well, even like the voting system...

Yeah.

... that's pretty good, because even if it's sort of three similar questions...

Yeah.

... with the same process every time, if I do the first one and get it wrong, and then if she goes through it, then I do the second one, then I'll know roughly where I'm going with it.

Yeah.

So I can see whether I did understand it, or whether I understood it but just don't remember exactly what step goes next.

Yeah.

So I can sort of base it on how well I'm getting on.

The downside to this strategy, which is essentially a procedural surface approach is, as K9 pointed out, that a student might become 'stuck' if a question is presented in a way such that the formula learnt would not be applicable:

Ok. You know, sometimes if you memorise a formula, and the question, you expect a similar, a similar, a certain kind of question with a formula. And let's say they changed the components a little bit, you know, it doesn't really –

I get stuck.

You get stuck.

Yeah.

192

And so, do you, to overcome that, what do you think you can do?

Um, well, if you, if you literally just learnt the formula, there's not really, sorry, there's not really much you can do. Um, whereas if you sort of have learnt the formula but roughly understand about it, then if they've changed a particular element of it, you can change, like, sort of use what you know, really.

5.7.6 STRATEGIC LEARNING APPROACH

The written comments of K9 on the pre-interview questionnaire indicated that K9 had adopted a strategic approach at A level. This was indicated by his/her statement that s/he avoided pure mathematics subjects and instead concentrated on mechanics so as 'to bring up my grade' (see below). S/he had also indicated on the pre-interview questionnaire that his/her goal was performance-related (i.e. the aim for a 55% score), in part so s/he could have the option of pursuing a postgraduate degree programme:

You're going to be in trouble. Yeah. The second question here, I wanted to know if you were looking forward to starting maths at Loughborough before you came to Loughborough. And you said 'I was good at mechanics at A level and I've been told...' So –

I was just, I was told before I came to Loughborough by my teachers at my old school that it was fine because I did really well in mechanics at A level...

Yeah.

... and it was an engineering course, so it would be all about mechanics, so that would be fine. And I got here, and last year it was all about matrices...

Yeah.

... and integration and vectors...

Vectors. Yeah.
... and all the stuff that I wasn't particularly good at when I was at school.
Ok.

But I, I, because you only needed to get a grade for, um, to get in, for...

For entry [At the same time].

... to get in to the first year...

Yeah.

... so I concentrated on mechanics because I knew that was what I could do to bring up my grade.

Yeah.

So I didn't really go over the stuff that I wasn't good at...

Yeah.

... because I didn't think I'd need, I was told I wouldn't need it, so –

Further, s/he also displayed strategies that were targeted at maximising her performance on assessments. In the excerpt below, K9 again talks about the practise of solving problems, this time in preparation for the coursework assessment, which helped him/her to identify the 'patterns' for solving the problems:

Ok. For the two tests you've taken on the MAB104 module, how did you revise for that? For those two?

Um, mainly going through the workbooks.

Yeah.

Um, the first test, there was one written, sort of, paper. Like a practice paper, that I did. Whereas the second one, there was, um, tests on learn, which were really helpful, because you can do the tests as many times as you want...

Yeah.

... and it'll give you answers for every single one.

So you did this?

So I did some of those.

Ok.

Um –

And what did you learn from doing those? Is that the same with the patterns?

Again, with the patterns.

Ok.

You know, one question, I had no idea where I was going with it. I knew that, you know, there was …… [Indistinct] but I really did not know exactly which one fitted to where.

Yeah.
But after a while, like, the pattern emerged and then it became really obvious while I was doing everything.
Ok.

Um, and I didn't, I don't think, I didn't do as well as I'd like to have done in the last two tests, but I think that's because of negative marking and silly little mistakes.

Ok.

But I understand it so much better than some of my other modules.

Strategy: Revising for Examinations

Similarly K9 explains below that s/he prepared for examinations by working through the examples and exercises with solutions that are provided in the HELM workbooks. In addition, s/he also worked through past examination papers as well as the practice tests that are available on the University online resource, LEARN:

Ok, for the exam, how are you preparing for the exams?

Um, a lot of different ways. I mean, again, with the tests on learn and the practice tests, we've got, um, practice papers from, like, past years, like...

Yeah.

... that I've been going over, and I've been go, in the workbooks, I've got worked examples...

Yeah.

... which I looked at before I read through and it made sense. But now I've been using those as test questions as well. Sort of, you know, you've got the question at the top and obviously the working, so even if I get stuck...

Yeah.

... I'll go through the working and see which bits I got right and which bits I got wrong.

5.7.7 SUMMARY

The study skills adopted by K9 appear at first glance to be predicated on rehearsal strategies with the goal of reproduction. Moreover, K9 provided no indication of an intention for understanding on the pre-interview questionnaire. However, the evidence presented suggests that K9 adopts rehearsal strategies as a means of achieving conceptual understanding later in the learning process. K9's learning intention is therefore subsequent understanding, although this is predicated on a reproduction orientation that is epitomised by the use of rehearsal strategies. Further, K9 also employs a strategic approach towards assessments as evidenced by his/her focus on practicing past examination papers, with a view to identifying 'patterns', and

demonstrates evidence of EI as s/he was acutely aware of which topics to focus on based on evidence from his/his review of past examination papers.

In summary, K9 could be characterised as largely displaying a procedural deep approach to learning (Table 5.6). This is based on a combination of his/her stated intention for subsequent understanding and the focus on rehearsal strategies. However, his/her approach is also characterised by procedural surface strategies, especially when s/he is pressed for time or lacks the relevant proficiency for solving a problem. Embedded in K9's approach, therefore, are elements of not only procedural deep but also procedural surface as well as strategic approaches. This is an instance of the presence of a triad approach or 'disintegrated approaches' (Meyer, 2000) in the approach of a student to learning.

Interviewee - K9	Characterisation
ALT	Intention: Procedural Deep In Practise: Procedural Deep + Procedural Surface
Goal Theory	Performance
Strategic Approach?	Yes

Table 5.6 Characterisation of K9's approach to learning mathematics.

5.8 INDIVIDUAL LEARNING APPROACH – K2

5.8.1 INTENTION CRITERION

The goal of K2 according to his/her submission on the pre-interview questionnaire is to: 'Get a real understanding of course and get above 70%'. The expression of an intention to understand by K2 is further buttressed by comments such as the one below, where s/he started by talking about his/her awareness of the need to work hard so as to 'get a real grasp of the concept':

But even though in the real world you sometimes like, tend to slack off and don't do what you have to. But still I know that in the back of my mind that I have to work hard, because I, I'm not the most brilliant student on my course, but I know that if I work hard enough, and I get a real grasp of the concept, then I can do well.

So for you it's important to get a grasp of the concept?

Yes, it is.

Further, K2 continued by asserting that s/he 'tries and understand' but acknowledged that s/he sometimes fell short of this requirement. S/he reiterated that s/he preferred 'understanding the concept' because that is better suited for long term memory, and subsequently better recall:

In maths, some people just have to know the formulas, you don't need to understand what's happening...

That's true, that's true, um... It has happened to me as well and I try and understand. I think if you understand the application of, of a particular formula...

Yeah.

... then you know how it works. And when you know how it works, it's easy to, you know, um, apply it.

Yeah.

And... But sometimes I agree with you that I do like to just get the numbers and put them in the formula and get the answer. I do that as well.

What do you prefer? Which one do you prefer?

I prefer understanding the concept, because when you understand the concept, that goes a long way. 'Cause then you can apply the concept in the future as well...

Yeah.

... whereas the formula, you might remember, you might not remember, so you...

Yeah.

... don't know.

In summary, K2 demonstrates intention to understand based on evidence from both the pre-interview questionnaire and interview transcripts. In the next section, I would present interview excerpts that would illustrate the strategies that K2 adopted, with a view to determining whether the strategies represent a reproduction or mastery orientation.

5.8.2 STRATEGY CRITERION: USE OF EXAMPLES

On the pre-interview questionnaire, K2 stated that his/her strategy for achieving his/her goals or intentions as stated above was hard work:

'I believe hard work is the key to success, so if I work hard I know I can achieve what I desire.'

However, that is not an indication of a specific strategy. In the interview, K2 stated that the main strategy that s/he employs in developing his/her proficiency at solving problems is the use of examples. S/he said that having access to examples also helped him/her overcome any language barriers to understanding lecture content:

Yeah, I think I agree with that, um, in terms of application. But how do you get to understanding the concept? What do you do to get you to understand the concept?

I look at... I go for examples.

Yeah.

Like, if I know how the example works, then I would know how it works, how the whole thing works. So the example is the best thing for me. Even... The thing is, for me, English is not my first language, so in the lecture, there are some times where I don't understand what the lecturer is saying.

Yeah.

And it's not only for maths, it's for all of the modules that I do. So what I do is, when the time is right, I just look at examples and then I try and figure out what I have to do perfectly. And then I do it in the tutorials as well. So, this is hard work.

So you look at examples... and do you do... personally then now go at your own leisure time, you go over the questions again and try to solve them?

Yeah, yeah. Well, I try to, I do, like...

Although K2 stated that s/he employs examples as a way of understanding the concepts, a critical look at his/her comments suggest that his/her goal appears to be reproduction of *what works*. As s/he stated above: 'If I know how the example *works*, then I would know how it *works*, how the whole thing *works*'. So s/he uses examples as a template for practising or rehearsing how to solve the problem.

5.8.3 INFLUENCE OF TIME

It seems that time influences the type of approach that some students adopt to learning. As K2 relates here, when s/he was pressed for time, s/he decided to adopt a procedural surface approach, as that was quicker:

And for the test, I did not apply myself to the concepts. I just went 'ok, this is how you do it', and I just kept on –

Why was that?

Sorry?

Why was that?

I didn't have time. I... 'cause at that time I had three courseworks to finish and the test, so I didn't have time. So I just did the practice test. And I got a very good at it, 'cause it's very straightforward.

Perhaps because students know they have a choice, especially for mathematical tasks where they might be able to employ a formula to solve a problem, they might be more likely to choose a largely procedural (surface) approach when pressed for time:

Ok. So for you... sometimes you have this choice between using the concept approach, or just using a formulaic approach. If you have time, you go for the concept, is that right?

Definitely, yeah.

But if you don't have time –

I go for the other one.

You go for the formula one.

Like I said, for this test, I didn't have time, so I just went to the other approach.

Yeah.

I didn't... I got a good grade in the test but, like I said, sitting right in front of you, I can't do it right now.

5.8.4 EVIDENCE FOR STRATEGIC APPROACH

As stated earlier, EI is the ability of students to infer from cues from the learning environment about which aspects of the module to focus on in order to maximise

performance in assessments. For instance, K2 demonstrates EI by indicating that s/he knew which kind of questions were likely to appear in exams, and was confident that questions such as Q1 (Figure 3.1) were not likely to appear:

The volume? The volume, ok. Good. That's good. Before I go on to the second one – now when you see double integrals – those kinds of formulas which we just had – is it going to make you think about what it might mean in the physical world? Or would you just forget about it all?

Sort of.

Sort of, yeah. Very good.

But not in the exam, I'll be honest with you.

Not in the exam?

Because you don't have time – you have to just do it.

Yeah. Makes sense.

I know for a fact that she's not going to ask this question in the exam. That's just forbidden, to base your concepts on it.

Why – is it too easy?

No, it's not too easy. It's a very tricky question.

Yeah.

But the thing is, it's not going to be in the exam. The exam is going to be pure mathematics. Ok, this is pure mathematics as well, but it's a physical... it's based on the physical attributes of ...

I get what you mean. Don't worry, yeah. The second question... and, um,

Oh, I don't remember this.

One of the ways students develop EI – in this instance, knowing which questions were likely to feature in the examination - is by reviewing past assessment papers. As K2 stated, 'You can know that by looking at the past papers. If you look at the past examples, you know the pattern, you see the pattern":

didn't... I got a good grade in the test but, like I said, sitting right in front of you, I can't do it right now.

Yeah. Another thing that you said is that everything you do, this question, this topic is likely to come up in the exam. It's likely to... Like this one, you said it might come up in the exam. For the first question, you said that might not come up.

Yeah, that was, uh, that was just to make us realise that, what are the physical, like, how is integration in a physical way.

Yeah.

You don't get those types of questions in exams.

So when you looked at the question, you said, 'this type of question won't come up in the exam', you might not be as motivated to pay as much attention to it –

Yeah.

... as another question you say there's a greater likelihood that it'll come up in the exam.

You can know that by looking at the past papers. If you look at the past examples, you know the pattern, you see the pattern.

Yeah.

And then you can see that 'ok, these are the types of questions there are going to be' and you have to prepare in such a way. So usually what I do when I've covered all the topics, I go over the exam. I don't just solve it, I just see the types of questions there are. And then I just start doing it according to the exam.

Limitation of rehearsal strategy

One problem with the approach above is that since it is based on identifying and reproducing the patterns identified from past examination questions, long term recall is sacrificed. As K2 indicated ('... I got a good grade in the test but, like I said, sitting right in front of you, I can't do it right now'), s/he could not recall how to do a question from a test in which s/he had done well. Another problem with the approach above is if the exam structure suddenly changes substantially in a particular year and without prior warning, then the student might flounder. Further, one of the links between EI, the adoption of a strategic approach and assessment is that assessment structure and composition may influence which topics students focus on:

All the questions we've had have been used in class. This is polar coordinates, do you remember?

No. We just did it very, very briefly and then, this wasn't even involved in the test. So we didn't really pay attention to it that much.

Ok.

Polar coordinates, no.

So how did you know it wasn't going to be in the test, did she tell you anything?

201

No. But I've done the test so I know it wasn't in.

It wasn't there.

And it wasn't there in the practice test as well.

A consequence of the adoption of a strategic approach is that a student might have a pseudo rating system on which topics to prioritise for learning and revision. Therefore, students might not give much attention to some topics, just as K2 stated 'we didn't really pay much attention to it [i.e. a topic] that much'.

5.8.5 SUMMARY

The study skills adopted by K2 appear predicated on rehearsal strategies with the goal of reproduction. Apart from his/her overtly stated preference for mastery of material or attainment of conceptual understanding, there is no indication from the strategies adopted that K2 has an explicit thrust for mastery or conceptual understanding. Moreover, s/he admitted that, when pressed for time, s/he often adopted an approach that was devoid of an intention for understanding. Further, K2 demonstrates evidence of EI as s/he was acutely aware of which topics to focus on, based on evidence from his/her review of past examination papers.

In summary, K2 could be characterised as displaying largely a procedural deep approach to learning. This is based on a combination of his/her stated intention for understanding material and the predominance of rehearsal strategies. However, K2's approach is also characterised by procedural surface strategies, especially when s/he is pressed for time. Embedded in K2's approach, therefore, are elements of not only procedural deep but also procedural surface as well as strategic approaches (Table 5.7). This is an instance of the presence of a triad approach or 'disintegrated approaches' (Meyer, 2000) in the approach of a student to learning.

Interviewee - K2	Characterisation
ALT	Intention: Procedural Deep In Practise: Procedural Deep + Procedural Surface
Goal Theory	Performance
Strategic Approach?	Yes

Table 5.7 Characterisation of K2's approach to learning mathematics.

5.9 INDIVIDUAL LEARNING APPROACH – K1

5.9.1 INTENTION CRITERION

On the pre-interview questionnaire, K1 stated that his/her goal or intention for the module was to obtain a 'high 2:1 for module' while for his/her degree programme, s/he was aiming for a '2:1' grade:

Ok. Thank you. What's your goal for, is it your goal for the module to get a pass grade for, I mean, to get a 2:1?

Yeah.

That's for your degree.

Um, yeah.

For this module, though.

For this module. Um, a high 2:1, yeah, for this module.

And what, what percentage would that be? The high 2:1, maybe I'll go and figure that out.

It's 60 something.

Ok.

It's about 68.

Ok. You say to achieve that goal, which is a high 2:1, you say you need to participate in lectures, attend tutorials, look over notes of lectures. So, you don't, you normally have the Wednesday and Thursday lectures?

It should be noted that there was no mention of an intention to understand course material either here or later on during the interview. In the next section, I will present K1's strategies, with a view to determining whether they epitomise elaboration or rehearsal.

5.9.2 STRATEGY CRITERION

K1's stated strategy (as indicated on the pre-interview questionnaire) for his/her realizing his/her goal of a 'high 2:1 for the module' was to 'Participate in lectures and attend tutorials. Look over notes after lecture'. Note that these do not refer to specific strategies. However, observation of K1's attempts at solving a series of problems or questions presented during the interview proved very insightful. It should be noted that I was *not* evaluating the impact of the questions on the approach adopted by K1. Instead, I was looking at aggregating or identifying patterns/commonalities in terms of the approach(es) that K1 adopted *across* the whole spectrum of questions s/he was required to answer.

5.9.3 EVIDENCE FOR PROCEDURAL SURFACE APPROACH

Observation of the approach of K1 to solving Q3, Q4, Q6 and Q5 (see Figures 3.3-3.7), indicated that his/her strategy was that, even for the questions s/he could not recall being used in class, s/he always wanted to identify the right pattern, procedure or method to getting the question right.

Here is how K1 indicated s/he would have solved Q3 (although s/he did state that s/he could not remember exactly how to go about solving the problem):

Ok. And seeing this question, what comes to your mind? If you look at it and you're trying to solve it, what do you think you need to do?

Um, just take two lines, from here, one, that, the negative gradient one and the positive one and then try and see how, um, 'cause one part of that represents one of those lines and the other one's...

Yeah.

... the other one. Um, and then just the equation of a line.

Yeah. Ok. Can you just... Sorry. If you wanted to attempt it, what would be your answer?

Um... I think 2.

Yeah.

Without any working out. 'Cause I can't quite remember, I can't remember the equation of a line but I'd say 2.

So, you think that you've got to understand the equation of a straight line?

Yeah.

K1 seemed to imply that s/he could not work out the solution to the problem above because '…I can't quite remember, I can't remember…'. S/he therefore seemed fixated on recalling the formula or pattern for solving the problem rather than evaluating what the problem required and attempting to solve it based on this knowledge. Similarly, his/her approach to solving Q4, when s/he could not remember the product of sinpi was to use a calculator instead:

Ok. Now, this is another question.

Hm.

It's been a long time. That's lecture 12. That's what they all mean.

Yeah.

Which, under which topic does this fall? This is not sort of –

Um, I think we did this in...

Not the sub-topic. Generally.

I think it was in Fourier series...

Yeah.

... when you're trying to work out whether to use an or bn.

Yeah.

Yeah. Well, some of them simplify to 0 when you expand.

Yeah.

Um, this was probably one thing that I didn't quite get at first.

Ok. Why didn't you get it? What were you struggling with?

Um, just remembering which one's which. So I'd probably be tempted to try and use a calculator for it.

205

Again, K1's approach to solving the problem indicated above was about 'remembering which one's which' i.e. accurate recall of the *right pattern* for solving the problem. In the excerpt below, K1 demonstrates the same approach to answering Q6, which is a vector calculus-based question:

So, what do you think the answer is?

I can't remember which way round it is. 'Cause I know some of them, you take the whole, um, like, the whole expression...

Yeah.

... for each, and then differentiate it with respect to either x, y or z. And then some of them, you just take, like, the first, I think it's –

Do you remember grad, the grad?

Grad, yeah.

What, what does it give you?

The, is it rate of, um... I can't remember the terminology. I think I know what I mean, 'cause I remember her showing –

Is it a scalar or a vector? The outcome?

The outcome's a vector.

A vector or a scalar? Ok, try to see, get the question and see...

Ok.

... what you come up with.

I think it's a scalar. It's 2.

It's a scalar?

Yeah, 2. **[s/he got the answer wrong]**

Twice s/he indicated that s/he could not answer the question because 'I can't remember which way round it is' and 'I can't remember the terminology'. Moreover, s/he explained that s/he had just been focusing on doing the calculations to get the answer to Q6, to the detriment of thinking about the question, which was probably why his/her strategy was 'remembering which way round':

Ok. You're doing ok, right? That's good. Like I said, it's not a test of knowledge, that's why I'm not really helping. There's another question on that one here. So, this previous one, what kind of difficulty do you think there is for anyone to answer that right? What kind of difficulties could they have?

Um, it's just remembering which way round, um, whether grad or div are scalar or vectors, but I think that's the point of the question, isn't it? So... But I think it forces you to think of probably what they represent rather than, um, rather than just learning the word, like div or grad and trying to just do a calculation with it.

Although K1 found the question on partial differentiation (Q5) fairly simple, his/her approach was still about, 'I can't remember which way round it is':

Ok. Since these ones are not there, so, let's go to this next one. Do you remember this one?

Yeah.

Why do you remember it?

Um, I think it's because I found it quite easy at the time.

Why did you find it easy?

Um, well, it's just, I think this one was just partial differentiation, is it?

Yeah.

Which we'd already done last year, so this was...

Ok.

... a nice topic to finish the year on.

So, what do you think the answer is?

I can't remember which way round it is. 'Cause I know some of them, you take the whole, um, like, the whole expression...

Yeah.

... for each, and then differentiate it with respect to either x, y or z. And then some of them, you just take, like, the first, I think it's –

Do you remember grad, the grad?

Grad, yeah.

What, what does it give you?

The, is it rate of, um... I can't remember the terminology. I think I know what I mean, 'cause I remember her showing –

Is it a scalar or a vector? The outcome?

The outcome's a vector.

A vector or a scalar? Ok, try to see, get the question and see...

Ok.

... what you come up with.

I think it's a scalar. It's 2.

It's a scalar?

Yeah, 2.

It therefore appears that K1's general approach to solving problems is about identifying the relevant patterns, without any stated or implied emphasis on conceptual understanding (although it should be stated that K1 had not revised the module material as at the time the interview occurred, so s/he was a bit rusty). Therefore, K1's strategies are characterised by a focus on rehearsal.

To establish whether or not K1 demonstrated intention for (conceptual) understanding, I am adopting the position of Case and Marshall (2004) who posited that it seldom occurs that a student with an intention to understand would fail to convey this, either explicitly or implicitly during an interview about their approach to learning or solving problems. For example, some students were characterised as displaying a procedural surface (or 'algorithmic') approach to learning because none of these students 'even commented in the long run they thought they would develop understanding through this [i.e. algorithmic] approach' (Case & Marshall, 2004; Case, 2000). The fact that K1 did not express an intention for understanding at any time during the interview could therefore be construed as an indication of a focus on the use of rehearsal strategies that is devoid of an understanding orientation.

5.9.4 SUMMARY

Based on K1's preoccupation with pattern identification together with the associated adoption of rehearsal strategies, and lack of any evidence of a stated or implied intention for understanding, I am characterising K1 as largely displaying a procedural surface approach to learning. Further, I did not find any evidence of a strategic

approach. A summary of the approaches to learning, which incorporates the frameworks employed in evaluating K1, is presented in Table 5.8.

Interviewee - K1	Characterisation
ALT	Procedural Surface
Goal Theory	Performance
Strategic Approach?	No evidence

Table 5.8 Characterisation of K1's approach to learning mathematics.

5.10 INDIVIDUAL LEARNING APPROACH – K5

5.10.1 INTENTION CRITERION

On the pre-interview questionnaire, K5 listed his/her intention for the module as 'Get a real understanding and a good pass!'. Hence the intention to understand is ostensibly present. Later, s/he clarified the 'pass' goal by stating what s/he was aiming for, as according to him/her, 'anything under 80% is not good'.

K5 further validated the presence of the intention to understand when s/he declared, 'I first understand what I'm learning and then understand how to use it', as expressed below:

So before you were saying the motivation for you is to find out the mathematical subjects and find how you can apply them to a real life situation from an engineering perspective?

Yeah.

Would that be correct?

Yes.

Ok. So, you were saying before that you need to be able to understand for you to be able to do something, like a mathematical concept?

Yes.

Like a topic?

Yes. I couldn't just accept a fact just because I'm told, you're a mathematician, so you tell me that's right and I'll just go and use it.

Yes.

I'd like to understand it before I just take it from you and apply it basically.

Yeah. Let's take for instance the question about the straight line.

Yeah, what about it?

If you understand that formula you can apply it the same time you have a problem...

Yes.

... but that doesn't necessarily mean that you understand the concept.

Oh yeah, I still... I would like to understand the concept as well as...

So you, your goal is usually to understand even when they present another topic like eigenvalues or multiple integration, you want to see, not just apply the formula, wait to apply the formula, but how did you get to know it.

Yeah. I first understand what I'm learning and then understand how to use it...

K5's claim that s/he seeks first to understand a concept before s/he learns how to apply it i.e. 'I'd like to understand it before I just take it from you and apply it' implies an intention for *concurrent* understanding.

5.10.2 STRATEGY CRITERION

One of K5's strategies is to seek help as soon as s/he could in resolving any learning difficulties. For instance, when a situation occurs in which s/he did not get the answer to a question in class, his/her approach was to try and work out the solution by following the instructor's feedback, or else by either going to see the instructor for help in person or by going to the tutorial:

So. Let's say, the other side, when you get it wrong, and you're not feeling too good – what do you do after that?

Um, I usually go back and just work out where I went wrong and why I did it wrong...

Yeah. Let's stay in the class for now.

In the class I'd go through it again.

As C is going through it... Because usually C goes through the solution...

Yes, she does.

... so when she's going through it, then you're following, and you're trying to see if you can make the amendments you made, the corrections you need to make.

Definitely, yes.

And suppose... Does that help you solve the problem?

Oh definitely. Definitely, yes.

But I'm sure there are times where that wouldn't be sufficient.

Oh, the thing is, it's not that difficult because C is always open so, you know, if that's not sufficient or if the time is up and the lecture is finished she's always there to help, so I've never found a problem with it.

So you go to her, make an appointment or something and go see her?

No, I just go and see her. No, just after the lecture or during tutorial groups.

Ok. So that's your plan, if you don't understand something, you don't wait. You go to see her after that particular lecture?

Or the next tutorial.

The next tutorial. [At same time]

Or if I can, in between, if I can do it on my own, I'm happy then.

It should be pointed out that the instructor confirmed that K5 had often come to see her about learning issues germane to the module. Moreover, K5 stated that s/he reviewed his/her work on a regularly, and implied that s/he was not in the habit of letting his/her work accumulate:

Yeah. I use maths as a different thing, um, I use maths to get my brain to concentrate or I often do maths, say, at the weekend if I've got a lot of work to do. I start with maths, get me to concentrate for a couple of hours, I do some work, some examples from the workbook... Um, if I need to go back to the lectures I go back to the lectures and, you know, make sure I understand. Um, but yeah, it is a subject that I do do regularly – I don't leave it.

This approach to addressing gaps in understanding in a timely and efficient manner is an expression of a mastery or meaning orientation towards learning.

5.10.3 COMPREHENSION MONITORING: QUICK AND DELIBERATE CHECK

Another characteristic of K5's approach is the adoption of a dual mode of answering questions, as a sort of *comprehension monitoring* mechanism. There is the quick option, which is more or less an elimination strategy, which is to evaluate relatively quickly whether from the parameters given, it might be possible to identify the correct answer(s) from a list of options. Then there is the more deliberate or thorough option where the steps to deriving a solution are not skipped, but each element of the question is considered in arriving at a solution instead of guessing at it.

During the interview, K5 said on at least one occasion that s/he needed time to switch from the first to the second. In the exchange below, the quick answer strategy were characterised by comments such as 'I'm not thinking about it…' and 'I wasted a lot of time trying to make a guess':

This is the wave we were given to answer that?

To answer this question, yeah.

Yeah. Oh right, sorry, yeah. So I'm not working out Fourier series, I've just to answer this question?

Yeah, definitely.

Sorry. Ok.

Do you think this question is going to take some time?

No. No, it's number 2 I think.

Why is it number 2?

Hang on a second. Give me 2 seconds. It's not. Because I'm not thinking about it, I'm trying to eliminate.

So when you see...

It doesn't work. None of them work.

So you think it's a trick question?

It is.

Why would you say it was number 2? Why did you first say it was number 2?

Um... why? Because from 0 to pi I knew it's a negative gradient and from the other half of the period it's a positive gradient and I knew they would be pretty similar, so I'm trying to make a guess but I'm not doing a very good job. So I'd rather work it out properly. Like here, I wasted a lot of time trying to make a guess.

The adoption of comprehension monitoring or elaboration strategies, as highlighted above, is an expression of a mastery or meaning orientation.

5.10.4 STRATEGIC APPROACH INCORPORATING ELABORATION

The comments below indicate that while K5 is focused on developing mastery, s/he is at the same time interested in scoring good marks. Hence s/he goes through HELM workbooks for examples that would help improve his/her speed in thinking about and solving problems. Revision of past papers also helps him/her identify 'tricky' questions:

First class is 70.

Yeah. So it's got to be 80 or over , that's good. So this one, that's why I wanted to talk to you on record. And you your goal – there are two goals – you need to get a real understanding of the maths and get a very good grade.

Ok, yeah.

And to get a very good grade, what do you do?

I use the workbooks a lot because they have a lot of examples...

Yes.

... so I do them even if they're easy because they give me... they just make me faster at thinking and solving the problems.

Yeah.

Yeah. And just to get good marks I do past exam papers...

Is that for the exam or coursework? Do you get good marks. I mean, you do past exam papers – that's for the examination, to show your targets or strategies. Do you do a lot of exam papers? Why do you do exam papers?

I only do a couple –

Why do you do that?

Because, um, usually during exams there is always some catch questions that make you think. In the workbook, although there will be some difficult questions, but they are all like straightforward.

Yes.

Um, but in past exam papers there's always some catch questions here and there.

So it kind of prepares you for what to expect?

Yes, it prepares you for what to expect.

However, s/he stops doing past questions as soon as s/he has identified the relevant patterns, usually after working through two or three papers. According to him/her, this is so that s/he would not just be 'learning questions' which, according to him/her, does not aid understanding:

When you're going through past questions, you start seeing patterns, sometimes. Is that seeing similar questions, expressions?

Especially if it's the same lecturer, yes.

Yeah. And does that help you to get an understanding of what you... what the subject is or it just lets you know what to expect –

No, it just helps you to pass, it doesn't help you...

Just helps you to pass. So, when you start preparing for exams, you're not necessarily aiming to understand, you're aiming to pass well. Did you get that question? You know, you do this, lots of past question papers and sometimes you start seeing patterns in what you expect...

Yes. I give up then.

You give up? What do you mean by that?

I normally do two or three past exam papers and if the pattern is always the same, I stop because I don't want to start learning questions because it's not helping me understand. I'd rather stop there.

Ok.

Yeah.

This is an indication that his/her approach is characterised by the adoption of deliberation strategies. This is why s/he stated s/he does not want to 'start learning questions because it's not helping me understand. I'd rather stop there', perhaps because s/he is aware of the limitations of embracing that approach. In the exchange below for example, K5 highlighted a flaw of adopting a procedural surface approach, namely significant memory loss about how to solve a problem. In contrast, s/he pointed out that it was easier to either retain or recall facts learnt through a grasp of the concepts:

... we want to see their different approaches, some people just like, they don't have to understand. They don't want to or they don't like it – and there's nothing wrong with that. Because sometimes for maths you can get good scores, a very high score and you don't really understand what's happening.

Yeah but there is a problem to that –

What's the problem?

If you do that way, you go away from it and then you forget it all. Well, if you know where it comes from and you understand it –

Yeah?

Even if you forget a little bit, but, you know, if you read up to refresh your memory, you can refresh your memory very easily.

5.10.5 SUMMARY

K5 has a very explicitly declared intention for concurrent understanding i.e. s/he first understands something before trying to apply it. Further, s/he takes steps to address gaps in his/her understanding of relevant subject matter, employs a comprehension monitoring approach towards problem solving, and avoids an overreliance on rehearsal strategies e.g. review of past examination papers. K5's approach to learning may therefore be characterised as conceptual deep (Table 5.9). Further, s/he displays strategic approach as well because of his/her practice of reviewing past examination papers so as to identify recurring patterns and 'tricky' questions to focus on. S/he was also aiming for 'a good pass' i.e. 100% in the module examination.

Interviewee - K5	Characterisation
ALT	Conceptual Deep
Goal Theory	Mastery
Strategic Approach?	Yes

Table 5.9 Characterisation of K5's approach to learning mathematics.

5.11 DISCUSSION

Using a multiple theoretical framework consisting mainly of the ALT framework, but incorporating constructs from both goal theory and strategic approaches, I have characterised individual interviewees' approaches to learning mathematics. Although only four of these characterisations were presented in this section, the remaining six interviewees were evaluated using the same characterisation procedures presented earlier. A summary of the characterisations for the 10 interviewees is presented in Table 5.10.

Interviewee	ALT	Goal Theory	Strategic Approach?	Overall Grade
K1	Procedural Surface	Performance	No	82.7
K2	Procedural Deep	Performance	Yes	70
K3	Conceptual Deep	Mastery	Yes	72.4
K4	Conceptual Deep	Mastery	Yes	48
K5	Conceptual Deep	Mastery	Yes	88.8
K6	Conceptual Deep	Mastery	Yes	62.8
K7	Procedural Deep	Performance	Yes	73.4
K8	Procedural Deep	Performance	Yes	86.4
K9	Procedural Deep	Performance	Yes	48.1
K10	Procedural Deep	Performance	Yes	65.7

Table 5.10 A summary of the characterisations of interviewee learning approaches based on the ALT, strategic, goal theory and TTW frameworks.

Characterisations of learning approaches via the integrated ALT framework indicate that five, i.e. half of all interviewees, displayed a procedural deep (PD) approach (Table 5.10). This might be attributed to the procedural deep affordance of the course context, as would be shown in the next chapter. A relatively high number of interviewees (i.e. four students) were also characterised as displaying a conceptual deep (CD) approach. I

think this might perhaps be related to the fact that all the interviewees had indicated in their pre-interview questionnaire submissions a positive attitude, enjoyment and/or aptitude for mathematics (see Chapter 6.2.3.2). Although I did not sample the opinions of the rest of the class, it is quite reasonable to assume that in a class of 156 students, there are some who would not display such positive attitudes towards mathematics, and who might therefore be disinclined towards aiming for (conceptual) understanding of a subject they do not enjoy.

It can also be seen from Table 5.10 that all but one interviewee employed the strategic approach, irrespective of whether they adopted a PD (i.e. performance goal) or CD approach (i.e. mastery goal). This is in contrast to classic goal theory where students with a mastery orientation are not expected to display an overt focus on assessment. An explanation for this overt focus on assessment by even students with a CD approach or mastery orientation is the postulation by Pintrich, Conley and Kempler (2003) that students with mastery goals 'might use the standard of getting a better grade than others (usually seen as an aspect of a performance goal) as an indicator that they have mastered and learned the course material'. Further, Pintrich and Garcia (1991) indicated how 'in the reality of the classroom students can endorse both mastery and performance goals and different levels of both of these goals' (as cited in Pintrich, Conley & Kempler, 2003).

In the next section, I will discuss some of the issues that are germane to the analysis and results of the characterisation process.

5.11.1 STUDENT APPROACH AND PERFORMANCE

I have included the overall grade of each interviewee (Table 5.10). In addition, a comparison of interviewee grades with the rest of the class is presented (Table 5.11). This is to enable a contextualised interpretation of interviewee overall grades. The data shows that the mean (overall) course grade for the interviewees is about 10 percentage points higher than the rest of the class (Table 5.11). So the ability of the 10 interviewees as a cohort is relatively higher.

The reason for the inclusion of these grades, which only became available six months after the completion of the interviews, is to identify any relationship(s) between the type of learning approach adopted and the corresponding academic performance. Data from Table 5.10 shows that the interviewees with the three best overall grades are K5, K8, and K1 who were characterised as displaying conceptual deep (CD),

procedural deep (PD) and procedural surface (PS) approaches respectively. This implies that student learning approaches do not appear to have any bearing on academic performance. The same pattern is repeated for the top five overall grades, which feature one student with a PS characterisation, two with a PD characterisation and three with a CD characterisation.

Further, of the six interviewees with distinctions (i.e. overall grades>70%), three of these are characterised as displaying a PD approach, two with a CD approach and one with a PS approach. Interestingly, K4, characterised as exhibiting a CD approach did poorly overall (along with K9 with a PD approach), perhaps indicating that a CD approach is not necessarily synonymous with high accomplishment on standard assessment measures.

	Coursework average	Exam average	Overall grade average
Whole class	64.7	58.4	59.7
Interviewees	75.9	68.3	69.8

Table 5.11 Comparison of the academic performance of the 10 interviewees with the rest of the class.

One possible implication of this outcome i.e. no discernible impact of the type of learning approach adopted on academic performance is that students might be unenthusiastic about embracing a conceptual deep approach, which is what is usually advocated (e.g. Haggis, 2003), if the 'pains' of adopting such an approach do not demonstrably lead to the 'gains' uppermost in students' minds – high academic achievement. If there are no perceived benefits, students might refrain from adopting comprehension monitoring or elaboration strategies in favour of an approach that emphasises reproduction or rehearsal. Ironically, there is a major disadvantage to this approach from the assessment perspective, which seems to be students' overriding concern.

5.11.2 DISADAVANTAGE OF RELYING ON REHEARSAL STRATEGIES

When the structure of an assessment (e.g. examination or coursework) that students have familiarised themselves with through rehearsal strategies is changed, students

often flounder. This was illustrated by K9's comments (Section 5.7.4) that students become 'stuck' when question or examination structure changes. As has been shown earlier however, students often adopt rehearsal strategies as a route to the attainment of (subsequent) understanding of learning material. In general, rehearsal strategies are useful because:

- The problem solving nature of engineering mathematics (as typified by the module being investigated) and much of applied mathematics require the use of procedures;

- Some concepts might only be understood after prolonged practice or use as K9, for example, explained in Section 5.7.4. This is because 'Learners… are often faced with tasks that do not have apparent meaning or logic. It can be difficult for them to learn with understanding at the start; they may need to take time to explore underlying concepts and to generate connections to other information they possess' (Bransford et al, 2000, p58).

Given the student fixation on (passing) assessment, perhaps one way to encourage understanding-incorporating approaches is to change the type of questions presented in examinations and coursework, from term/semester to semester. This could be accompanied by the rationale that the change is not to 'punish' students but to help them to learn the basic concepts of the subject matter, such that they would not become stuck when assessment content or structure changes. However, the adoption of an understanding-focused approach requires at least an initial (major) investment in time, and this would be the focus of the next section.

5.11.3 INFLUENCE OF TIME ON THE APPROACH STUDENTS ADOPT

One influence on the type of learning approach that students adopt that does not appear to have received much attention in the approaches to learning literature, apart from the research undertaken by Case and Gunstone (2003) and Marshall and Case (2005), is the time factor. Deemer and Hanich (2005), writing about how they restructured the undergraduate Psychology course they were teaching in order to emphasise mastery goal orientations (i.e. deep or conceptual approach to learning), commented that:

Mastery-oriented goals will most likely prevail when students feel ownership in determining the pace and scheduling of learning activities and assignments. For this reason, the pace of instruction and the appropriateness of the workload were discussed with students, and accommodations were made when deemed necessary. These accommodations were made for students who were devoting considerable effort toward completing course assignments but were struggling because they lacked

In essence, students were given control over the '*pace and scheduling of learning activities*' based on the realisation that they 'lacked skills' necessary for completing course projects, despite the fact that these students were devoting considerable effort toward completing course assignments. This is an indication that student with low proficiency in a particular subject matter would usually require time in understanding the relevant concepts or achieving procedural fluency. This was the same approach or attitude that the researchers on the Improving Attainment in Mathematics Project (IMAP) longitudinal study had about helping 'low-attaining students' to 'make deep progress in mathematics' (Watson et al., 2003). The authors, who reported that many of the low-attaining students made significant progress with respect to learning mathematics, described how the use of time by the teachers involved in the project contributed to students' progress. Some of the guiding principles or methods that the teachers adopted include:

- Provision of extended time for learning – some teachers were reported to have 'extended a single topic over several weeks in order to use many different representations…', while another teacher 'put no time limits on any tasks'
- Students could ask for more time to work on an exploration
- Speed as an indicator of mathematical proficiency was subtly discouraged, especially in cases where students had provided erroneous answers, as students were encouraged to self-check their answers

Further, the authors (Watson et al., 2003) summarised the view of the teachers as one that emphasised the judicious and often extended use of time to ensure deep progress towards learning, rather than covering the required material:

In general, teachers thought about the appropriateness of timing from the dominant point of view of learning, not from a dominant point of view of coverage. Rote-learning was avoided, although some aspects of mental arithmetic benefit from chanting and memory. There was a balance between time pressure used to encourage fluency and effort, and space used for thinking, reasoning, considering, reflecting. Covering the whole curriculum was important, but so was understanding what had been learnt. Working towards understanding is ultimately more long-lasting than mere acquisition of procedures. *(p24)*

It therefore appears that a shared perspective of both the Deemer and Hanich (2005), and Watson et al. (2003) studies is that to encourage a deep approach to learning, students with low proficiency or attainment often need extended time to master the requisite material. In the interviews with students, I presented fragments of conversations in which some of the students (e.g. interviewees K4 and K9) who explicitly stated their intentions for understanding learning material, often resorted to employing procedural surface approaches, because they did not have the luxury of the extended time that was required to arrive at a conceptual understanding of the relevant concepts.

In addition, it is not only students with low proficiency or attainment who need extended time for mastering learning material. Even 'seemingly talented individuals' require time to 'develop their expertise' (Bransford et al., 2000, p58). Further, lecture pace – how many topics are covered, and the time taken to cover these topics - play a significant role in the type of approach that students adopt. The authors of the (Bransford et al., 2000) study noted that 'attempts to cover *too many topics too quickly* [emphasis mine] may hinder learning and subsequent transfer because students (a) learn only isolated sets of facts that are not organized and connected or (b) are introduced to organizing principles that they cannot grasp because they lack enough specific knowledge to make them meaningful' (p58).

The influence of time on student approach to learning could be summarised in two ways. First, all students irrespective of proficiency or attainment levels would appear to require (at least initially) more time to engage with learning from a conceptual or deep approach perspective. Second, the time allocated for (guided) learning should bear a correspondence with the amount of material to be learnt because 'the amount of time it takes to learn material is roughly proportional to the amount of material being learned' (Bransford et al., 2000, p58).

5.11.4 METACOGNITIVE DEVELOPMENT SKILLS

As pointed out earlier, the learning approach adopted by students is often predicated on the perceived affordance of the course context. Case and Marshall (2004) noted how there was a 'convergence' towards the adoption of a procedural deep approach because students perceived the course context to 'emphasise problem-solving procedures over conceptual understanding' (p611). This context-dependent approach has been described as reducing the student to 'a human being without agency' (Haggis, 2003, p98) i.e. one

that can be manipulated to move in the direction of the course context affordance. A holistic option to facilitate learning with understanding might be to encourage the development of metacognitive or self-regulation (e.g. Pintrich & de Groot, 1990; Baird, 1986; Flavell, 1979) skills such as comprehension monitoring, 'self-evaluation of ideas, self-questioning when stuck, detection of errors…and considering limitations in their ideas' (Marshall & Case, 2005, p263).

Metacognitive development as used within this context implies a shift in student approach to learning, so as to accommodate learning with understanding (Case & Marshall, p608). So the student assumes *agency* for his/her own learning, with the intention of acquiring mastery of relevant learning material. One implication of this is that classroom instruction might have to be re-designed to take into account the need for students to develop over time discipline-specific, metacognition. Perhaps self-awareness and reflection skills might have to be built into the instructional process systematically such that over time students acquire the confidence and skills to proactively monitor and address gaps in their own understanding. The net effect would be that more students would not only take ownership of their own learning.

The regular use of EVS questions in lectures provides an example of how metacognitive development strategies might be incorporated into the instructional process. This is because regular EVS use facilitates deliberate practise (discussed in detail in Chapter Four), which 'emphasises the importance of helping students monitor their learning so that they seek feedback and actively evaluate their strategies and current levels of understanding. Such activities are very different from 'simply reading and rereading a text' (Bransford et al, 2000, p236).

In the next section, I will present the theoretical framework and analytical procedure I adopted for the secondary analysis of interview data.

5.12 SECONDARY ANALYSIS OF INTERVIEW DATA USING THE EMOBODIED-SYMBOLISM CONSTRUCT

The intention/strategy interface i.e. CAMC model was intentionally designed into the interview protocol (Chapter 3.2.4), with a view to using it as a means of characterising interviewee approaches to learning. To employ the TTW framework for the primary analysis of data would have required some TTW-dependent questions being incorporated into the interview protocol. However with the secondary analysis of data

approach I have adopted, I can still investigate aspects of student approach to learning by applying the TTW framework.

The outcome of the characterisations of student approaches using the integrated ALT framework showed that K3, K4, K5 and K6 employ a conceptual deep approach to learning. This approach is often presented as the apex or the desirable approach for students to adopt (Haggis, 2003; Devlin, 2007). But during the interviews, it was apparent to me that the *depth* of understanding displayed by these four students, based on their responses to solving the problems posed, varied. As the expanded ALT framework incorporating strategic approach and motivational goal theory did not provide any qualitative differences between these four, I decided to apply Tall's theory of three worlds (Tall, 2008), to evaluate whether there were any discernible differences in the depth of mathematical understanding displayed by K3, K4, K5 and K6.

As I earlier alluded, the main reason for limiting the application of embodied symbolism to the individuals characterised within the conceptual deep category was the fact that I observed during the interviews that the level of understanding displayed by K3, K4, K5 and K6 seemed to be qualitatively different. To determine whether there are any discernible differences in the depth of understanding displayed by K3, K4, K5 and K6, I will be applying the notion of embodied symbolism, which is a blend of embodiment and symbolism, in evaluating whether the depth of understanding displayed by the four are equivalent. Embodied symbolism simply means that students are able to conceptualise, through appropriate strategies such as visualisation, the embodiment i.e. real world or physical equivalent of the symbolic operations that they conduct to solve mathematical problems.

The significance of this approach, as opposed to the adoption of a purely symbolic method of manipulating objects is that the adoption of the former is an indication of a higher level of understanding of a particular subject area. Tall suggests that the adoption of a symbolic approach that is devoid of embodiment 'often involves a procedural approach, using rules rather than conceptual meaning' (personal communication, January 22, 2010)

Further, he suggests that the reason why students often struggle (e.g. Breidenbach et al., 1992) with moving from a *process* to an *object* level of conceptualization (Figure 5.1 and Table 5.13) is because students are unable to mentally represent or visualise the mathematical operation as an embodied entity or thinkable concept (Tall, in press).

To apply embodied symbolism to characterise the depth of student i.e. K3, K4, K5 and K6 understanding, I observed how these students responded to solving a question on double integration i.e. Q1 (Figure 5.3). Q1 requires that students have (a visual) understanding of the concept of double integration i.e. to solve the question by thinking of the double integrals as representing the volume under a surface. Where appropriate, I also considered student attempts at solving Q4 (Figure 5.4) where students, without using calculators, should be able to imagine or visualise the sine wave. In addition, interviewees sometimes commented on whether they were able to, preferred or loathed to, or were unable/not predisposed to using visualisation strategies. But the main evaluation strategy was how students responded to Q1. It should be noted therefore that the characterisations to be presented in this section are based on limited evidence.
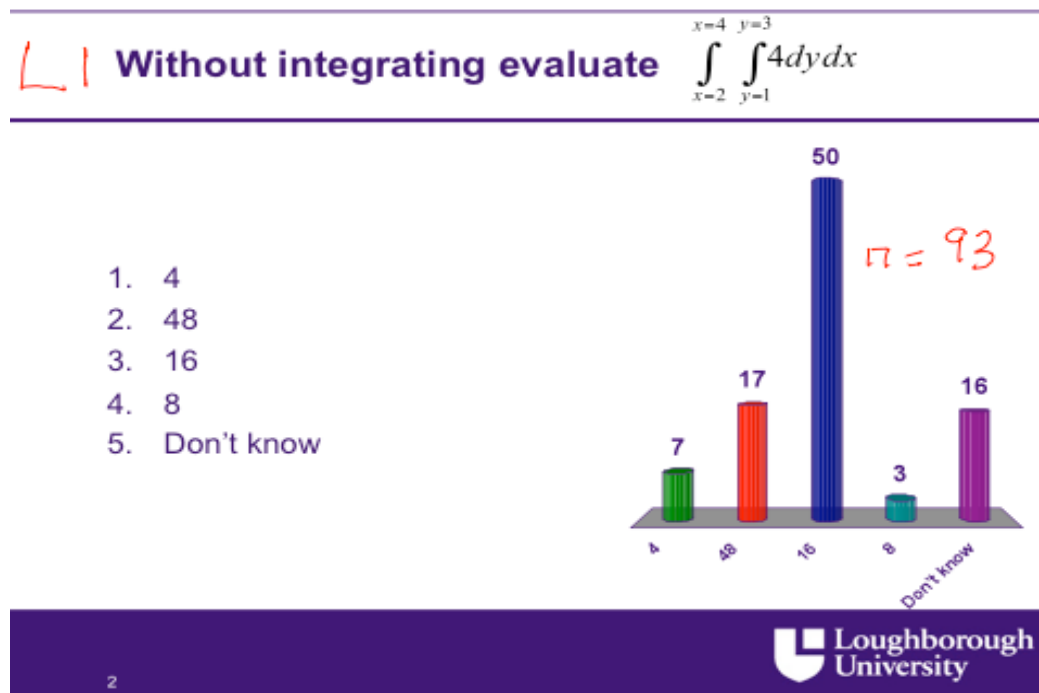
Figure 5.3 Q1 - An EVS question on double integration.
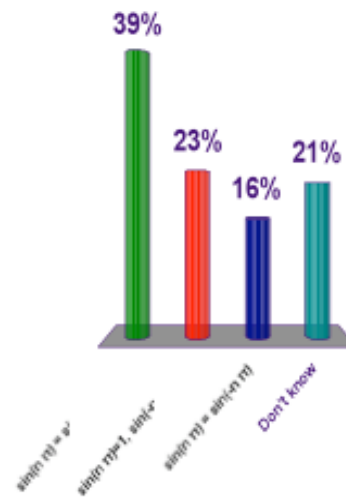
Figure 5.4 Q4 - An EVS question on sine calculation, knowledge of which is required for Fourier Series.

5.12.1 EMBODIED-SYMBOLISM (K5)

Before I present K5's approach to solving Q1, it is essential to present a brief background of how Q1 was used in the lectures. Q1 was presented in the very first lecture of the mathematics module being investigated, hence the inscription 'L1' in Figure 5.3. The instructor stated that she used Q1 to introduce the concept of multiple integrals to students because she knew from experience that students often find this topic difficult. She therefore reasoned that providing them with Q1, a relatively easy question, could be a good starting point for the introduction of the topic. When the students did Q1 in class, only about 54% (i.e. 50 students) got the correct answer. By the time K3, K4, K5 and K6 were re-presented with Q1 during the interview, they along with rest of the class had gone through a series of lectures on differential and integral vector calculus. So a certain level of familiarity with the concept of double integration was expected during the interviews.

The question itself required students to solve the problem without resorting to symbolic manipulation, hence the 'without integrating, evaluate' prompt. To successfully do this, a student has to be aware that the double integral represents volume, and that this could be derived through the product of the cross-sectional area

i.e. dxdy and the height (of the surface), given by the constant i.e. 4. This is the embodied-symbolic approach to solving the problem i.e. the ability 'to imagine the object before it is computed'. The other approach, the purely symbolic manipulation route, involves routine calculation.

When K5 was presented with the question, s/he came up quickly with the answer without any symbolic manipulation involved, suggesting the adoption of an embodied-symbolic approach:

No, I don't remember this particular question, no.

You don't have to remember. It's not a matter of you get a score...

Ok, yes.

And it says, without integrating the values.

Yes. It's 16 over 3.

Why is it 16?

Because the double integral is giving me the area of...

Yeah.

... the square of distance 2... Distance 2 which is 4 but it's multiplied by 4.

When I asked him/her to verify if s/he could envision a shape being formed from the boundaries of the integrals, s/he responded that s/he could *see* the *area*:

All I see is the area of a square times 4.

Area of a square times 4?

Well I suppose you could see it as a square of sides 2 and a height of 4.

K5's approach indicates the adoption of an embodied-symbolic approach. Moreover, s/he gave the answer very quickly (I noted in my interview notes that it took him/her less than 10 seconds to respond), which suggests that operating in that mode might have been instantaneous or reflexive for him/her. Similarly, his/her response to Q4 (Figure 5.4), which required students to be able to correctly represent or visualise the sine function, was quick:

It's 1. If it's sin npi.

It's sine npi. So why is it 1?

Because sin npi is 0, and although it's an odd function sine of -npi is also 0.

Now K5 was the fifth student that I interviewed. I had noticed with the previous interviewees that at least one of them got either Q1 or Q4, or both wrong. So I asked K5, as I did the later interviewees, why students would struggle with answering Q4. His/her response indicated that s/he thought that the reason was the fixation on symbolic manipulation through calculator usage to the detriment of being able to visually represent a sine wave:

Now, some people might... Let's say some people got this wrong – why do you think they would have gotten it wrong?

Because they don't understand sine and cosine curves.

So you need to be able to understand... at least in your head you need to be able to see or visualise the sine wave and the cosine wave...

Yes.

It's something like this.

Yeah. If you ask... in my course if you ask most people, if you ask them to evaluate sine and pi they'd use a calculator.

Why do you think that? Why do you think that happens?

Because in A levels or whatever they were shown how to draw that, they probably did it using a calculator.

SUMMARY: Observation of how K5 answered Q1 and Q4 during the interview indicates that s/he adopts an embodied-symbolic approach to solving problem, when necessary. Further, the adoption of this approach appeared to have been instantaneous on such occasions.

5.12.2 EMBODIED-SYMBOLISM (K4)

In contrast to K5, when I asked K4 to try and answer Q4, his/her approach was to try and do straightforward integration i.e. calculation. When I told him/her that the

question wording was, 'without integrating', s/he could not do it and admitted that s/he had become 'confused':

That's why I wanted... I would have told you not to write it down but since you always write it down I'm going to ask you without doing the calculation.

Ok.

Try to see if you can picture what's happening there and what you need to do.

Mm...

What are you trying to do?

I don't know. I'm confused now.

To help K4 out, I asked him/her to try and 'picture' the question, but this only seemed to have added to his/her confusion. His/her confusion seemed to stem from the fact s/he could not remember how to derive the solution without integrating:

Try to see if you can picture what's happening there and what you need to do.

Mm...

What are you trying to do?

I don't know. I'm confused now.

You're confused about something? Why are you confused?

'Cause I can't integrate it and I can't remember how to do it.

I'm not saying you should integrate it. Obviously you have to have some knowledge of integration, but try to see what's that telling you.

Oh man. I'm well confused.

K4 later admitted what the real problem was – s/he was generally poor at 'visualising' or 'drawing graphs':

I'm really bad at drawing graphs, like, visualising what it means as such.

Yeah.

Similarly, K4 could not answer Q4 because s/he could neither envision or draw the sine wave nor 'remember the rules':

To get this question, do you have to do something? Or what, what would you have to do?

I'm sure some people could just do it in their head – like, really logical people. But I would probably have to sit and work it out.

Suppose you wanted to sit and work it out, how would you do it? Now?

Yeah, I would –

I mean, I'm saying, try to do it.

Oh god. Ok. Try and remember my rules. Sine... [unclear muttering by interviewee] I'd probably need a calculator. I'm sure there's some easy way to work it out.

K4's need for a calculator to answer Q4 seemed to buttress K5's initial assertion that some of his/her classmates often resorted to using a calculator to circumvent the need for proper understanding of a concept when a rules-based approach using a calculator would lead to the solution of a problem.

      SUMMARY: Observation of K4's approach to solving Q1 and Q4 indicate that s/he displays a largely symbolic manipulation approach to solving problems. S/he seems unable or unprepared to accommodate embodiment or visualisation strategies when faced with problems requiring the adoption of such an approach. To clarify K4's difficulty with answering Q1, it is imperative to point out that s/he did state that s/he generally found integration difficult.

5.12.3 EMBODIED-SYMBOLISM (K6)

When I presented K6 with Q1, s/he employed a straightforward calculation (integration) method to answer the question:

Why is it 16?

Um, because... Shall I go back to the equation?

Huh?

Do you want me to go back to the equation?

Yeah.

Um, because if you dif, if you integrate the 4 with respect to y it becomes 4y. Then it's 4 –

When I requested that K6 attempt the question without integrating, s/he replied that s/he was unable to do so:

You're integrating.

But I don't understand. Is that not what you –

It says without.

I don't know how to do that question.

When I asked K6 why s/he could not attempt the question without calculating and what needed to be done to get students to answer similar questions, s/he suggested that the way a topic or problem was introduced in the lecture environment would influence how students approached similar problems:

... the context of the lecture would sort of do that. Because you'll have been doing questions that haven't involved integration. You'll have been doing it from graphs and things.

Yeah.

And then you'll sort of automatically do it like that.

Yeah.

If you're given, sort of, an equation, you just automatically see it as integration but 'cause it's in the context of a lecture, you would just automatically do it differently.

K6's suggestion that the context in which a topic is introduced influences related problem solving is an example of the conditioning induced by the notion of met-before. This implies that students who are given multiple opportunities to utilise methods comprising embodied-symbolic approaches are more likely to be proficient at using both symbolic manipulation *and* visualisation strategies than those whose instructional diet consists mainly of numeric calculation methods.

When I presented K6 with Q4, which were often presented to interviewees as the two related questions, Q4a (Figure 6.8) and Q4b (Figure 6.9) [both questions, which are examples of repeater type of questions – see Chapter 6.4.4, are based on the sine wave, with Q4b being easier to answer than Q4a], s/he got Q4a wrong but was able to

answer Q4b correctly. K6 got Q4a wrong because, although s/he was able to visualise the sine wave, his/her visualisation was erroneous the first time around:

You got it wrong and you could visualise the problem. But you visualised wrongly.

Yeah. I made it... Yeah, that was a really stupid mistake.

This portends that while the adoption of an embodied-symbolic approach is often an indication of greater understanding of a subject, compared to use of a purely calculation method, the approach is not without its difficulties.

     SUMMARY: K6 shows a limited use of an embodied-symbolic approach. S/he appears to employ largely symbolic manipulation methods for solving problems.

5.12.4 EMBODIED-SYMBOLISM (K3)

When I presented K3 with Q1 s/he, like K6, got the answer via symbolic manipulation:

Um, integrating between 2 and 4, one of three differences to be a 2, integrating 4 itself. Obviously it's probably not how I've said that.

K3 attributed his/her inability to answer Q1 'without integrating' to being 'stuck on method' or symbolic manipulation:

I find a question like this difficult because it says 'without integrating' and, 'cause I'm so stuck on method.

Yeah.

I find it diff... to most people that may be really obvious. But to me, I look at that and think, even if, there is a way in my head of going, I can get that...

Yeah.

... and it's as simple as, I still like to go and work my way through the page. So without integrating I find it really hard to look at that because I'm so stuck on methods.

     K3 further clarified the 'being stuck on method' admission by suggesting that this was due to the conditioning induced by previous teaching on calculations involving double integrals – the same reason proffered by K6:

It's what you've been, it's what you've been taught...

Yeah.

... and, what, like, how we've been shown to do it. But it's not the first one that jumps to my mind because of the way the education and academics of it is, it's just the way you work through it.

Yeah.

But if I was to look at it afterwards and say 'hang on a sec', I can almost, like, double check my answers and double check my work and say 'hang on a sec – that's a shape, it's 2 by 4'... like I said, the difference between those was 2, so it's 2 x 2 x 4 which gives you 16. So it's almost double checking my answer.

You double check your answer? How?

I've got a mathematics calculus and I've got my visual way –

So you do the mathematical one to get the answer? And then you use the visual one to double check?

Yeah. It's strange. Well, sometimes I do it the other way around, which should make more sense, to do the visual –

Further, K3's submission in the last paragraph above suggests that s/he often adopted what s/he called the 'visual approach' as a mechanism for verifying the 'mathematics calculus' method. This is an indication that while K3 did not employ an embodied-symbolic approach to answering Q1, s/he often utilises the approach. This is buttressed by his/her approach to answering Q4, which s/he answered by physically drawing the sine wave. K3 explained that s/he would usually visualize the requisite wave whenever s/he was faced with problems like Q4 where s/he was required to integrate a sine or cosine wave:

I think it's like number 1 but I'm looking again to see if it's got... It's definitely not number 2. It's definitely not number 2. It's definitely 1, it's definitely 1.

So why do you think, where do you think someone might have a problem with this?

Um, underst... I don't see any actual reason as to why there would be a problem. Um, if you're told, you're told not to use a calculator, you may not know how to visualise a sine wave.

Did you visualise the sine wave? Before I gave you the –

Yeah. I think that with sine, cos, even when I'm integrating and differentiating sine and cos, I draw down the sine graph and then think 'the gradient at the first point is 1, so then the gradients 0, so you go to 0'. Then I realise it's going like that and think 'that's a cos'. And for the cos one I just look at the gradient on each point...

Yeah.

... to get my mind of sine, and obviously let it –

You always do that? You always do that?

Pretty much every single time I've got to integrate sine or cos.

SUMMARY: K3 at first appears to be limited to the use of numeric calculation methods, based on his/her approach to solving Q1. But his/her attempts at answering Q2 and other comments provided indicate that s/he often adopts an embodied-symbolic approach to solving problems. S/he also indicated that would often use a 'visual approach' to verify solutions derived from symbolic manipulation methods.

5.13 DISCUSSION

Using the presence or absence of an embodied-symbolic approach as the main determinant, I have attempted to characterise the depth of understanding inherent in the approaches of K3, K4, K5 and K6 to problem solving. Based on the data presented, K5 seemed to have displayed the greatest use of an embodied-symbolic approach, which s/he often used in an instantaneous or reflexive manner. K4 on the other hand did not seem to utilise the blended approach, preferring to rely exclusively on symbolic manipulation methods. Both K3 and K6 employ the blended embodied-symbolic approach, although their readiness and dexterity at applying this approach is not as high as that displayed by K5.

Based on the limited evidence presented, it might be suggested that K5 displayed a high understanding of the concept of double integration (based on response to Q1), and a generally high usage of the embodied-symbolic approach – based on how s/he responded to Q1 but also Q2 and the other related comments s/he provided (Table 5.12). By the same logic, K4 exhibited low understanding of the concept of double integrals, and generally low usage of the embodied-symbolic approach. K3 and K6 could be viewed as having displayed a low understanding of the concept of double integration. However, their approaches to answering Q2 and their comments about incorporating visualisation strategies alongside symbolic manipulation methods suggest intermediate usage of the embodied-symbolic approach.

Interviewee (Conceptual Deep Category Only)	Understanding of Double Integration Concept	Usage of Embodied-Symbolic Approach
K5	High	High
K3, K6	Low	Intermediate
K4	Low	Low

Table 5.12 Illustration of how the Embodied-Symbolic approach illuminates student understanding of related mathematical concepts.

A possible explanation for K5's relatively high understanding of the concept of double integration, as evidenced by his/her answer to Q1, was that s/he was probably able to imagine the *effect* of the integration operation – that is, s/he was able to envision *what* the *final state* or *outcome* of the task would be based on the integration operation required. However, I can only conjecture this as the study was not designed to probe this reality. What is incontrovertible is that s/he envisioned the product of the integration as representing volume, or as s/he put it:

'I suppose you could see it as a square of sides 2 and a height of 4'.

The evaluation of interviewee understanding of the double integration concept based on attempts at answering Q1 therefore buttresses Tall's statement that 'symbolism without embodiment' often 'involves a procedural approach using rules rather than conceptual meaning (personal communication, January 22, 2010), as this statement or description applies to K3, K4 and K6. This is because anyone with an understanding of the concept of double integration and with prolonged exposure to working with problems involving double integrals should be able to answer Q1, a relatively simple question.

Both K3 and K6 suggested that their limited ability in using the blended approach was due to the met-before of previous teaching, especially in calculus where students are taught to solve problems almost exclusively via symbolic manipulation routines. They implied that a greater use of instructional methods emphasising blended approaches would probably lead to an increase in the number of students adopting

visualisation and calculation strategies. In fact, K5 alluded to this when s/he remarked that previous teaching (at A level) was probably responsible for the inability of some students to answer Q4:

Yeah. If you ask... in my course if you ask most people, if you ask them to evaluate sine and pi they'd use a calculator.

Why do you think that? Why do you think that happens?

Because in A levels or whatever they were shown how to draw that, they probably did it using a calculator.

S/he then implied that s/he was able to answer the question i.e. develop an approach comprising both symbolic and visualisation strategies because s/he had not been allowed to use a calculator (in the country where s/he studied):

It's very simple, I was never allowed a calculator, so it's different for me.

A more detailed discussion of how calculator usage influences student approach will be presented in Chapter 6.5.

It should be noted that the adoption of a blended approach is not without its peculiar difficulties. It has already been noted that a wrong visualisation led K6 to the incorrect solution with respect to answering Q4a. K3 had also stated that s/he could not answer Q5 (Figure 3.6) in class and also during the interview because s/he 'got confused by the visual aid' used by the instructor. This is why researchers in the field of object-process theories often caution about the use of visualisation strategies, due to its ability to introduce defective knowledge (Breidenbach et al, 1992; Tall, 2008; in press, 8-8) or faulty intuitions (Fischbein, 1993). Further, the use of the embodied-symbolic approach might not accommodate problems involving numbers with negative values or very high dimensions (e.g. signed numbers or numbers with powers greater than three – see Tall, in press, 8-13).

In summary, a blended approach involving both visualisation and symbolic manipulation strategies, as has been shown in this section, can be a powerful way of illuminating student understanding. Hence, concerns about potential pitfalls on adopting visualisation strategies should not lead to a situation whereby the baby is thrown out alongside the bath water. Instead, embodied-symbolic approaches should be adopted with a view to representing the problem, such that the evidence is seen in 'such a way as to get good intuition' (personal communication, January 21, 2010). Moreover,

the 'long term development of mathematical thinking benefits from the development of a rich knowledge structure that blends embodied meaning and flexible symbolic operations to solve novel problems' (Tall, in press, 8-15).

5.13.1 COMPARISON OF THE THREE WORLDS AND ALT FRAMEWORKS

In terms of mapping the integrated ALT framework to the TTW framework, the only clear categories in both frameworks that have a one-on-one correspondence are the conceptual deep (ALT) and process (TTW) categories. This is because the descriptions of the learning intention/process occurring at both the conceptual deep and process categories are analogous. The process category within TTW is described as being 'relational' i.e. 'relating several aspects together' (Table 5.13). Similarly, students with a conceptual deep approach are characterised by the 'relating of learning tasks to their underlying concepts or theory i.e. relating new information to existing knowledge' (Table 5.10).

By the same logic, it is reasonable to assume that students who are at the 'procept' level (i.e. Level 4 in Table 5.13) within TTW display greater understanding than those within the conceptual deep level on the ALT scale. However, it might be that the conceptual deep scale also incorporates students whose levels of understanding have evolved to the procept scale. However, I cannot verify this, as this study was not designed to capture this nuance. Last, it is reasonable to assume that the surface, procedural surface and procedural deep levels within the ALT framework broadly correspond to the procedure and multi-procedure scales within TTW.

ALT Framework	Procept Theory Description (i.e. TTW framework)		Levels of Understanding
Surface Procedural Surface Procedural deep [*Performance*]	Procedure	Uni-structural: responding in terms of one aspect	Level 1 (lowest)
	Multi-Procedure	Multi-structural: responding in terms of several aspects	Level 2
Conceptual Deep [*Mastery*]	Process	Relational: relating several aspects together	Level 3
?????	Abstract (Procept)	Extended abstract: having an overall grasp of the situation	Level 4 (highest)

Table 5.13 Comparison of the ALT framework with Procept Theory i.e. Tall's three worlds of mathematics.[26]

5.14 CONCLUSION

This chapter was designed to answer the research question, What is the student's approach to learning mathematics? To answer the question, I employed a primary analytical process consisting of the approaches to learning (ALT) theoretical framework, motivational goal theory and as a supplement, the strategic approach construct to analyse data from 10 interviewees. The ALT and goal theory frameworks which were combined, were patterned after the intention/strategy model, whereby interviewees' expressed intentions for learning and the associated strategies were used

---

[26] Data drawn from Tall, in press. Used with permission.

to characterise their learning approaches with respect to the procedural surface, procedural deep and conceptual deep learning approach categorisations.

The results of the characterisation process, using the integrated ALT framework, indicated that one interviewee displayed a procedural surface approach, four displayed a conceptual deep approach and five exhibited a procedural deep approach. I have explained that the greater frequency of the procedural deep approach might be due to the problem solving context of the mathematics module. I have also explained how an over-reliance on rehearsal strategies, as well as the (non-)availability of time influence whether or not students learn with understanding. In addition, I have highlighted how a focus on the development of metacognitive skills might provide a suitable means for students to take ownership of their learning, so they could study with understanding.

I have also employed secondary analysis of data whereby I evaluated the level of (conceptual) understanding of four interviewees, characterised as displaying a conceptual deep approach, by examining whether or not these interviewees employed embodied-symbolism, a construct from Tall's three worlds of mathematics theoretical framework. The results of the analysis showed that the four displayed varying levels of the application of embodied-symbolism, with the degree of application serving as an indicator of understanding of relevant subject matter. The degree of application of embodied-symbolism also appeared to mirror student academic performance, as the two interviewees who were unable to use embodied-symbolism strategies performed poorly overall in the module assessments.

The contributions of this study include the unique application of a multiple theoretical framework to analyse student approaches to learning. This has helped to provide a richer description and documentation of the procedures that may be used to reliably characterise student approaches with respect to the ALT framework. Second, the application of secondary analysis of data through the use of the embodied-symbolism construct extends knowledge of how even students characterised as displaying a conceptual deep approach to learning may vary in their levels of understanding of subject matter. Third, using a qualitative interview approach to analyse student approaches to learning provides an alternative view of investigating student learning in a field where the predominant means of inquiry is the use of inventories.

In conclusion, I have presented evidence in this chapter on the type of learning approaches that students adopt towards mathematics at the course level. In the next

chapter, I will present evidence on how specific EVS question types, as represented by the questions presented in Figures 3.1-3.7, tend to elicit different learning approaches at the task level.

CHAPTER SIX

THE IMPACT OF THE USE OF ELECTRONIC VOTING SYSTEMS' QUESTIONS ON STUDENT LEARNING APPROACHES

6.1 INTRODUCTION

In the previous chapter, I presented student learning approaches at the *course* level, using a multiple theoretical framework. In this chapter, I will present evidence on how the use of EVS questions has influenced student learning approaches at the *task* level - the distinction is that how students approach a task e.g. question or problem is not necessarily the same as the one they adopt at the whole course or module level (e.g. Case & Marshall, 2004). The impact of the use of EVS questions on student learning approaches will be presented from the perspective of the approaches to learning theoretical (ALT) framework only. The results presented are based on the analyses of interviewee transcripts, and are designed to answer the research question, How has the use of EVS questions influenced (or otherwise) student approach to learning mathematics?

The structure of this chapter is that I will first present the course context for the mathematics module from which the interviewees were drawn. This will be followed by a description of the pedagogical context in which EVS questions are used, which I refer to as formative teaching. I will then present evidence or indications of how the use of EVS questions have impacted student learning approaches. In the next section, I will discuss how the use of calculators influences student learning approaches, especially with respect to problem solving or (the acquisition of) procedural fluency. This will be followed by a consideration of how the use of guesswork influences student approach to learning, particularly in regard to the use of EVS questions, and the implications of guesswork adoption for student learning. The chapter concludes with a summary of the main issues discussed.

6.2 COURSE CONTEXT

Research indicates that student perception of the course or module context [course context here refers to an individual course or module within the English system] is influential in determining how students approach learning, especially at the course level (e.g. Ramsden, 1988; Crawford et al, 1998; Case & Marshall, 2004; etc). To determine whether the course context of the engineering mathematics module on which the students who participated in this study are enrolled elicits a surface or deep approach to learning, I employed the following strategies:

- Review of the course or module specification, incorporating the Intended Learning Outcomes (ILOs) for the module;
- Review of assessment structure;
- Review of comments from respondent submissions to the question, 'Would you say the way or rate you are learning on the module is similar or different to the way or rate you are learning in your other modules? Why is this so (Please explain) on the pre-interview questionnaire;
- Review of comments made during the course of the interviews about student perception of learning on the module and any factors responsible for this.

The rationale for the inclusion of the course context is to provide a 'thick description' or context within which the results of the interview study introduced in Chapter Three, and especially the results of the characterisation of student learning approaches presented in Chapter Five, may be appreciated.

6.2.1 MODULE SPECIFICATION

It is apparent from the Intended Learning Outcomes (ILOs) section of the module specification (See Appendix F) that the focus of the module is on problem solving. For instance, under the 'subject-specific skills' section, the keywords are 'evaluate' – which is used to describe six skill groups (e.g. ability to evaluate double and triple integrals) and 'identify/find', which are used to describe four skill groups or competencies that students are expected to possess at the end of the course. Further, under the section, Knowledge and Understanding, there is some sort of tacit acknowledgment that

students have to understand the concept of multiple integration to be able to 'find volumes, masses, centres of gravity and moments of inertia'.

The focus is on problem solving because the mathematics module is designed for engineering students whose main rationale or purpose for studying mathematics is to find out how they may apply mathematical principles to engineering problems. Moreover, the engineering departments are satisfied with this approach, which is what they advocated - see Croft (2002), Croft and Ward (2001), and Croft et al. (2000). However, this approach does include a raison d'être to understand - that is, to understand how the procedures were derived, and how they may be applied to real world problems.

It should be noted that the sentence, 'An over-rigorous approach is avoided' under the 'Aims' section of the Course Specification describes the intention of the instructor to limit the extent that formal mathematics (i.e. proofs, axioms, definitions, etc) is incorporated into the course.

For instance under the topic Convergence of Fourier Series, the instructor explains the convergence criteria and how they may be applied, and illustrates this by presenting students with examples and problems and demonstrating the convergence of a particular series. However, there is no explicit attempt to explain how the convergence criteria were derived. One reason for this is that the engineering students, unlike their pure mathematics counterparts, do not necessarily have a need for this to be included in the curriculum. Moreover, only six lectures are devoted to Fourier series, whereas for a pure mathematics module that is taken by students majoring in mathematics, many more lectures may be devoted to the coverage of Fourier Series. In addition, a thorough presentation of proofs would involve the elucidation of concepts that are beyond the level of the mathematical knowledge of the engineering mathematics students.

In summary, the module focus on problem solving necessitates the emphasis on procedures, and hence the probable promotion of rehearsal strategies for finding, identifying and evaluating problems. However, the knowledge and understanding intent of the ILOs implies that the instructional goal is that students will employ rehearsal strategies with some level of (an intention for) understanding. Based on this consideration (see Table 5.5), the module specification maybe viewed as being designed to elicit a procedural deep approach to learning in students. But it is quite possible for a student to focus on the use of rehearsal strategies without any rationale for understanding or meaning.

6.2.2 ASSESSMENT STRUCTURE

The assessment regime for the module is structured such that two pieces of coursework accounted for 20% of the final grade, while the end-of-module summative examination accounted for the remaining 80%. Considering the high percentage of the examination as a total of the final grade, it is no surprise that almost all the students interviewed had developed a strategy (i.e. a strategic approach) for the examination, which was often but not always separate from the intention to develop mastery of the course content.

Two pieces of paper-based coursework, consisting of multiple-choice questions, were completed for the module under invigilated conditions. For one of the coursework pieces, students had the option of preparing for the paper-based assessment by completing computer-based tests, featuring questions similar to the one on the actual test, any number of times. This practice of taking revision or preparatory computer-based tests seemed to induce largely a procedural surface approach to learning. This was because some students commented during the interviews that when they took the tests, their strategy was often to identify, through repeat practice, the 'patterns', or isolate the procedures that were germane to solving particular questions sets.

The module examination structure, which consisted of four questions, from which students were required to answer three, seems to indicate an affordance for a procedural deep approach to learning. This is because the examination is structured such that the questions not only consist of direct procedural operations, but also include questions which require understanding of the concept being assessed. In Q2a (Figure 6.1) for example, *sketching* the region of integration requires a higher level of understanding of the concept of double integration than the largely procedural operations required for reversing the order of integration and evaluating it. Similarly, Q2b (Figure 6.1), which requires students to derive the limits from the sketch provided, demands a level of understanding (including visualisation) of the concept of polar coordinates that is not necessarily accessible to those who approach the task from a purely procedural surface approach.

2. (a) Sketch the region over which the following integral is to be evaluated:

$$\int_1^5 \int_{\frac{1}{2}(x-1)}^{\sqrt{x-1}} (x+2y)^{-\frac{1}{2}} \, dydx.$$

Reverse the order of integration and hence evaluate it.   [8]

(b) The area moment of inertia of a lamina of area A, about the x-axis, is given by $I_x = \iint_A y^2 dA$. Using polar coordinates, or otherwise, evaluate I_x for an annulus of inner radius 1 and outer radius 3 centered at the origin (see Figure 1).   [6]
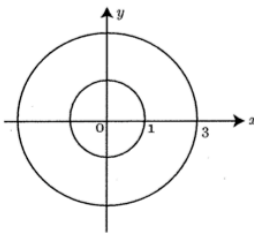
Figure 1

Figure 6.1 The second question from the module examination.

In summary, the assessment structure for the coursework appears to encourage a procedural surface approach to learning. However, the assessment structure of the module examination appears to elicit a procedural deep approach to learning.

6.2.3 STUDENT PERCEPTION OF LEARNING ENVIRONMENT

Analysis of student comments about the theme, perception of learning on the module' - from interviewee submissions to the pre-interviewee questionnaire (Table 6.1) and responses to the main interview questions - indicates four recurring sub-themes: Lecture pace, module structure, student attitudes towards mathematics, and teaching influence. These sub-themes will be presented in order in this section.

6.2.3.1 Lecture Pace

As much material has to be covered in a relatively short period of time, which is one of the reasons why formal mathematics is not given priority by the instructor, it might be expected that some students might view the pace of lecture delivery an issue. Three

interviewees: K2, K3 and K8 mentioned that the pace on the module is relatively faster than their other modules. However, K6 stated that there was no difference in pace. K2 later suggested, during the interview, that lecture pace may inhibit the intention to understand the underlying concepts:

Um, I think the learning process... So, what you mean is the lectures move so fast?

Exactly, we go really fast.

So is that a problem because you have so much load...

Exactly. It's not a very big problem but the thing is, in this, when you're going really quick...

Yeah.

... what happens is you sometimes don't get the concept. I mean, you don't get the concept, you just memorise the formulas. So that's what I'm saying in some... like, in two of the tests, there were like, two or three questions that I didn't really understand the concept properly. But what I did was, I just like came out with the formula and this is what I have to do, how you do it. So I just did that. So...

You were saying it's a problem that to understand the concept which is the way you prefer to work, you need some more time to link things together?

Exactly, exactly.

So you think you're pressured on the module? Compared to the other modules where there isn't much to do...

Actually, the thing is, mathematics has got tests, there are two tests this semester, yeah? Whereas other modules we have coursework, reports and all. So I would say that mathematics wasn't a big problem, it wasn't that much, just two tests and you had to prepare for it and then the rest is you just do for the exam. But for the coursework, you have to give more time, so I won't really be bothered about...

'Would you say the way or rate you are learning on the module is similar or different to the way or rate you are learning in your other modules? Why is this so (Please explain).

K1

'Better than other modules'

K2

'I think the learning process in MAB104 is a **bit quicker** compared to the other modules. This is mainly because of the amount of content that has to be covered in such a short period.'

K3

"Pace a lot **faster** during lectures but need to cement knowledge in own mind to learn subject thoroughly. **Enjoyable speed** of learning, as new topics all the time'

K4

'I learn best in MAB104. It's the one module I feel I actually understand. I think the **lecture structure** is different in mathematics and the fact that there are no notes given. I think writing everything down helps it go in!'

K5

'It is different mainly because **I feel mathematics is easier** than other modules. The **workbooks are very helpful.** Lectures well **structured**.'

K6

'The **teaching quality in MAB104 is exceptional.** This has been massively beneficial in lectures as I have found it more interesting, but it has also encouraged me to do additional work outside of normal hours. The **rate of teaching** is the same as (or similar to) other modules, but it has been more **thoroughly and more clearly explained**.'

K7

'I think it is different because I find **I can learn mathematics quicker and easier** and I feel it comes more naturally to me compared to other subjects.'

K8

'I would say the **pace is a little bit faster** than other modules covered. I feel that the numbers of topics and its contents are higher than other modules.'

K9

'I **find it easier** to revise this module as it is **put into sections (workbooks**). A lot of other modules is just 150 pages worth or revision making it hard to know where to begin!'

K10

'I would say it is more **suited to my pace of learning**, and I find that topics are **taught in a much more progressive way.** Whereas I find that in other modules, the content can go from being relatively easy to quite difficult very quickly.'

Table 6.1 Student views on the perception on learning on the module, as submitted on the pre-interview questionnaire.

I should point out that although some of the interview questions appeared to be leading, this was usually due to the relevant portions of the interview transcript being presented without the full context in which a (thread of) conversation took place. For instance in the excerpt earlier quoted, the question '…So what you mean is the lectures move so fast?' may appear misleading. But I made the remark because K2 had earlier written on the pre-interview questionnaire, 'I think the learning process in MAB104 is a bit quicker compared to the other modules'. So the leading question was in fact a reference to what K2 had earlier said.

In summary, a lecture pace that students perceive as being 'really quick', especially if students have a heavy course load, might encourage the adoption of a surface approach to learning. This is because students might resort to quick-fire strategies, such as short-memorisation techniques, with no intention of acquiring a deeper understanding of subject material. However, only three of the 10 interviewees perceived the lecture pace on the module as being fast or faster than other modules.

6.2.3.2 Student Attitudes to Mathematics

One feature that some of these students share is their affinity for mathematics – they might be considered mathphiles! K7 states for instance that, 'I find I can learn mathematics quicker and easier and I feel it comes more naturally to me compared to other subjects'. The implication is that students who display positive attitudes are far more likely to adopt a deep approach to learning than otherwise (e.g.). This is because students, and humans in general are more likely to pursue subjects that they find interesting or enjoyable. In contrast, they avoid subjects that are perceived as being tedious or unpleasant. In fact, research indicates that students who adopt a surface approach often endorse performance goals, which are characterised by effort-avoidant strategies (Fredricks et al., 2004). The implication is that students who do not have positive attitudes towards a subject are more likely to avoid investing time and effort in the subject, an investment that is often necessary for the attainment of deep or conceptual understanding.

In summary, the positive attitudes displayed by interviewees towards mathematics would indicate a preference for a deep approach to learning. However, I am uncertain as to how the positive attitudes towards mathematics displayed by the

interviewees are typical of the average engineering student (e.g. Kent & Noss, 2003; Hibberd & Mustoe, 2000).

6.2.3.3 Module Structure

Another salient feature of student comments is the structure of module material. There are companion workbooks for the module – the Helping Engineers Learn Mathematics (HELM[27]) materials, which students can use to do related assignments. These workbooks are aligned with the lecture material and also have problems with worked solutions. This is what K9 referred to in his/her comments (Table 6.1).

K10 also points out that the instructor introduces complex problems in scalable fashion. In addition, some past examination papers with worked solutions are made available on a dedicated university resource called LEARN, which students have access to. A positive impact of this structured approach is the admission by K6 that this has encouraged him/her 'to do additional work outside of normal hours'. The stated (student) preference for a structured approach is similar to the findings reported in Vermetten, Vermunt and Lodewijks (2002).

It is worthwhile to note that the positive perception of the module structure cuts across students with different learning approaches. For instance, K9, who often adopts a procedural surface approach and K5 who consistently employs conceptual deep approach both stated their preference for a structured module approach. However, it is possible that their motivations and/or appreciation of this structured approach may differ. In the study, Vermetten, Vermunt and Lodewijks (2002), the authors reported that students employing deep and surface strategies differ in the way they make use of instructional measures such as examples, workbooks, detailed manuals, etc. Therefore, the impact of module structure on student learning is an area for further research.

In summary, the limited evidence presented here suggests that the module structure, when viewed in the light of the ILOs, seems to encourage a procedural deep approach to learning. This is because students are not only required to solve problems regularly, they are also provided with readily accessible material and extra resources as learning aids. During the interviews (e.g. K9 and K4), students referred to how they used the HELM workbooks to resolve gaps in their understanding of a topic. The

---

[27] HELM (http://helm.lboro.ac.uk/) 'materials were the outcome of a three-year curriculum development project undertaken by a consortium of five English universities'.

provision of these workbooks and other resources within a clear structural context could only aid students in moving towards a deeper understanding of lecture material.

6.2.3.4 Teaching Influence

In Vermetten, Vermunt and Lodewijks (2002), the authors concluded that 'direct influence of instructional measures on learning processes does not take place'. But in the one course (Public Administration) where a positive influence of instructional measures on learning outcomes was reported, the authors observed how the deliberateness and approach of the lecturers involved might have been the deciding factor. Perhaps the quality of teaching and instructor's practices and beliefs are important factors that shape student perception of learning (see Watson et al., 2003; Ramsden, 1992; Laurillard, 2002).

In this section, I will present evidence on how interviewees perceived the teaching of the module by the instructor. I should point out that the fact that this section is longer than the other ones is merely a reflection of the volume of comments, which were unsolicited, by students about their perception of teaching on the module.

My position is that teaching exerts an important influence on student attitudes towards mathematics. For example, K4 (who stated that 'I learn best in MAB104') illustrates the importance of the teaching/teacher influence when s/he narrated how, during A level, two teachers had very different types of impact on his/her learning: one positive, the other negative. One, labelled, a 'horrible teacher' contributed to his/her 'hating' mathematics while the other somehow 'gave me a passion for, like mathematics':

Yeah. Like, when I first got there, I was told that I didn't have the skills, like, necessary to succeed in mathematics by this horrible teacher. And I really, like, hated it for a while...

Yeah.

... and then I changed my teacher and he made me see that mathematics is, like, fun. It was awful. But, yeah, I don't know why I enjoy it. I think it was the teacher I had. He just gave me a passion for, like, mathematics. I don't know why, it's such a weird thing to like….Yeah, I think his passion for the subject kind of rubbed off on everyone in his class. It got me an A.

Ok. Because of that experience would you say you were looking forward to starting mathematics at university?

Yeah. I would. 'Cause, like, mathematics... he showed us that mathematics could be actually, like, useful. 'Cause, like, our old teacher, he was like 'oh, mathematics – just do it...

Yeah.

... and get a good grade'. But, like, I don't know, now it seems so, like, useful and every subject we do here pretty much involves some kind of mathematics...

Yeah.

... so it's like, it's quite good. It is my favourite module.

You said here it was your favourite module at college?

Yeah it was. Just 'cause of the teacher... the rest of the modules were just, like –

Echoing K4's sentiments above, K6's comments implied that mathematics became his/her favourite subject in the 2008/2009 academic year because of the teaching quality as indicated by the clear explanation provided by the instructor:

So would you say mathematics is a favourite subject of yours?

Um, it has been this year.

Are there any reasons for that?

The teaching quality's been really good.

What about the teaching quality – is it the way they explain it, or about the pace –

Um, they go to a similar pace as all the other modules, but it's so much more clearly explained.

Ok.

Um, and then you can, we're using the voting systems, which is really handy as well. Just to see how you're getting along in the lecture.

Yeah.

Also makes you pay a lot more attention because you're going to get asked a question.

So it actually makes you pay attention because you know they're going to ask questions?

Yeah, yeah.

In relation to the module being investigated, K3 commented that s/he found the instructor personable and friendly, and that s/he eschewed an authoritarian approach to teaching without losing (the teacher's) 'voice' or authority in the process:

Ok. And what do you think about when C goes through a solution? Like, a question was wrong, whether it was wrong or right, she always provides feedback on what happened, this is the way it should be. What do you think about the feedback you get from C?

She's got a very good persona in the way she teaches. I do like it – it's friendly, it's kind, yeah, it's 'I'm the teacher – listen to me'. She's also open to opinion.

Yeah.

And she admits that everyone makes mistakes and she's done a couple. And it's all about practice. So, she's not one of those people who says 'I'm the teacher, I'm right' but there is the authority of 'I'm the teacher, listen'.

Another spontaneous comment about the personal attributes of the instructor was in relation to the module structure. K5 commented that the instructor came across as being 'very organised':

And you said that the workbooks are very helpful and the lectures are well-structured. What do you mean the lectures are well-structured?

Um, it's different from other modules... Um, I don't know. The mathematics lecturer is very organised and when she says she's doing ABC she is doing ABC and the workbooks are there to complement and give more examples etc. We don't have any of that in any other module, basically.

So it makes it easier for you?

So that's why it's a lot easier, it's just, you know.

Where does voting systems fit into that structure?

Um, just basically making a better use of my time during lectures because, um, I'm not sure whether it's the voting system that permits more examples to be solved during the lecture.

And the voting system is just a way to see, to show you how it's done.

Yeah. But it's there, it's computer, it's tidy and it makes you work.

The quality of the teaching was another aspect that interviewees commented on. K6 stated that the teaching was clear, the instructor taught with the aim of helping students understand the material, and that these motivated him/her to do extra work outside of class:

But the teaching quality is exceptional. So you say it's exceptional. What's that, what do you mean?

What do I mean?

The teaching quality on the module is exceptional.

Exceptional. It's just very good, it's outstanding.

It's outstanding. Why?

The, sort of the teaching manner, it's just so much more clear than other subjects.

Ok.

You can, I don't know why this is, but you can always clearly hear what the mathematics teachers are saying…

What they're saying. Yeah.

… and they'll always go to an effort to make sure you understand what they're saying.

Yeah.

And why they're saying that.

And here, it's very significant. You say the teaching style encourages you to do additional work outside of normal hours.

Yeah.

Why is that?

Um, it's just that, with other subjects, the tutorials aren't that exciting, the lectures aren't that exciting, and you think 'I can't really be bothered'.

Yeah.

But with mathematics, you know, I've done all the tutorial work before I go to the tutorial, which I don't always do…

Yeah.

… um, and I just find it more interesting,. You feel like you're achieving something out of it along the way.

Other comments on the teaching quality, this time from K10 and K5, focus on the use of 'practical examples' that students can relate to, especially considering their engineering background and aspirations, by the instructor so as to ensure understanding of the subject:

But did you find the pace on it to be quicker than the other modules?

Um, I didn't actually, I found, I thought, I find this module easier than the last module that we did. I don't know if it's 'cause of the, um, the topics, r maybe just 'cause of the lecturer, but I find the lectures, I find better. Just in general.

What's the difference?

I don't know. Um, I think probably just a better lecturer this, I just find our lecturer this module better than the one we had –

How? That's what I mean.

Um, I think she real, I like the way she's related a lot of things to, um, actual practical things. And she made sure that we, um, she made sure that you got an understanding of why you were doing something...

Yeah.

... and what practical use was, and actually what, like, 'cause sometimes mathematics can be quite abstract and you don't really understand what you're doing.

Yeah. So you don't like abstract mathematics? You prefer to see the practical application?

I'd like to know what it's actually, what this mathematics process does rather than just doing something for the sake of it.

Further, K5 indicated that, compared to other (i.e. engineering) modules, more examples were covered on the mathematics module:

You also said that more examples are covered in lectures – is that a result of the voting systems?

I'm not sure actually, um, it's just by comparison to all the modules, we do a lot more practical examples in mathematics than in other modules...

Yeah.

... and I wonder whether, because they don't have to write them down, they're all on a computer and it's quicker to do, quicker to vote...

Yeah.

... I'm not sure whether that's why we do more examples.

In summary, teaching may influence student learning approaches in two ways. First, the enthusiasm and passion of an instructor for a subject may 'rub 'off' on the students such that it might influence them to adopt positive attitudes towards

mathematics. This could in turn induce them to invest more effort in understanding the subject. Second, instructor's pedagogy, for instance, the use of examples or questions deliberately selected to help students move towards conceptual understanding of a topic, could potentially influence student learning approaches.

6.2.4 SUMMARY

Overall, the course context for the module appears geared towards inducing in students a procedural deep approach towards learning mathematics. This is because the ILOs, the clear structural framework for the module and instructor's pedagogy, such as the use of examples and the provision of extra resources in a timely and readily accessible manner, are designed so students could solve problems regularly, thereby increasing their procedural fluency, but also they gradually come to terms with the underlying concepts. However, there are elements of the course context, such as the lecture pace and the availability of practice coursework tests, that may encourage the adoption of a procedural surface approach.

In the next section and as a prelude to presenting evidence on how the use of EVS questions has influenced student learning approaches, I will present the pedagogical framework i.e. formative teaching for the use of EVS questions in mathematics lectures, as used on the module.

6.3 FORMATIVE TEACHING

Formative teaching refers to the intentional design and creation of a learning environment where active student questioning and feedback are an integral part of the lecture experience for students in a class. This approach is a variant of the Question Driven Instruction (QDI) paradigm (Beatty et al., 2006), a variant because peer discussion is not a major goal – although students on the engineering mathematics module being investigated have often been asked to discuss their answers with their peers. A typical lecture might feature up to eight EVS multiple-choice questions, depending on the topic and the learning outcomes envisioned for that particular lecture. A critical component of this teaching paradigm is the provision of suitable feedback in response to student submissions to questions.

In general, implementing the formative teaching paradigm requires:

- Identification of the topics/sub-topics that students routinely find difficult, common student misconceptions, incorporation of feedback from (previous) EVS questions, etc. This is an iterative process within the formative teaching paradigm;

- Creation and design of (good) questions – this should lead to the attainment of the learning outcomes by students. However, this is the most difficult part as creating really good questions takes considerable skill, time and (voluminous) practice (Boyle, 2006; Beatty et al., 2006);

- Adoption of an effective approach, based on teaching style preference(s) and theoretical ideology. It is possible to have two lecturers applying formative teaching, but with one more demonstrably effective in engaging students than the other, based on differences in delivery e.g. pedagogical content knowledge (Shulman, 1986).

Lecturers using EVS have commented that the most challenging aspect of incorporating EVS into their classrooms is the appropriate use of questions (King & Robinson, 2009c). This is because creating, designing and/or finding good questions that would enable the learning outcomes for a particular module to be achieved takes considerable time, effort and skill. Further, staff have to balance these demands against the background or desirability of completing the required course material within the stipulated period.

My classroom observations of EVS use in lectures for the engineering mathematics module (MAB104) being investigated shows that the following six types of EVS questions have been used to create an active questioning and feedback learning cycle by the instructor:

- *Teasers (Ice Breakers)*: These are ice breaker type of questions which can be used to create a relaxed atmosphere in class, such as at the beginning of a semester when students are new to one another. Teasers were not regularly used for this module, so I would not be elaborating on their use further;

- *Revisions:* These may be used to identify student prior knowledge, prior to introducing a topic that would build on this prior knowledge. Revision-type questions may also be used to highlight common student misconceptions;

- *Introducers*: These may be used for two purposes. They may be used simply to prepare students for the introduction of a new topic i.e. *direct introducers*. Second, they may also be used to introduce a topic, such that it gets students

thinking in a different way about a particular topic than they are accustomed to i.e. *conceptual introducers*;

- *Applications*: These are used to assess student efficacy in applying previously covered or recently introduced material;

- *ConcepTests*: These are used to assess conceptual understanding of a topic deemed fundamental, or one where there is evidence students usually have difficulty understanding;

- *Repeaters*: This is when a question, which students found difficult at the first attempt, is repeated in a slightly varied mode later in the semester to assess improvement in student understanding of the concept assessed in the initial question. Repeaters are also known as paired questions.

It should be noted that the characterisations above are subjective, in that they are a product of my evaluation of the types of EVS questions that have been used in lectures. This evaluation was based on the structure of the questions, and the purpose or rationale for their use, which I deduced by discussing with the module instructor.

A comparison of the question types presented above with the revised Bloom's Taxonomy (Anderson et al., 2001; Bloom, 1956; Carneson et al., 1996) indicates the corresponding cognitive level of the questions on Bloom's. Revisions are on the Comprehension scale because 'at this level, knowledge of facts, theories, procedures etc. is assumed, and one tests for understanding of this knowledge' (Carneson et al., 1996). The same logic applies to direct introducers. Applications are on the application level because the learning objectives at this level include the ability to apply 'laws and theories to practical situations, solve mathematical problems ... demonstrate the correct usage of a method or procedure' (Carneson et al., 1996).

ConcepTests and conceptual introducers appear to correspond to the Analysis scale because questions at this level are designed to assess the 'ability to break down material into its component parts so that its organisational structure may be understood' i.e. seeing the whole picture from its constituent parts (Carneson et al., 1996). Moreover, this description appears analogous to that for students described as aiming for conceptual understanding (i.e. the conceptual deep category in Table 5.5). Proficiency at this level should enable students to, for example, recognise 'logical fallacies in reasoning' and 'evaluate the relevancy of data'. Repeaters are usually an instance of the other types. So the Bloom's equivalent of a revision type of question that is being repeated to assess level of student progress (which in effect makes it a repeater type of

question), would be Comprehension. A summary of the comparisons of EVS question types with Bloom's Taxonomy is presented in Table 6.2.

EVS QUESTION TYPES	BLOOM'S TAXONOMY EQUIVALENT	DESCRIPTIVE VERBS
Revisions/Direct Introducers	**Comprehension** (i.e. test for understanding of knowledge)	Classify, convert, describe, explain extend, give examples, interpret
Applications	**Application** (Ability to apply laws and formulae to solve mathematical problems)	Apply, compute construct, demonstrate, discover, modify, operate, produce
ConcepTests / Conceptual Introducers	**Analysis** (Seeing the whole picture from its constituent parts)	Analyse, relate, associate, discriminate, distinguish, infer, order, separate

Table 6.2 Correspondence between the EVS question types and Bloom's Taxonomy[28].

Although I have used a qualitative approach to characterising questions here, a more quantitative approach may also be utilised. For example, ConcepTests are often assessed for their impact on students' conceptual understanding through quantitative measurements. This will typically feature both pretest and post test assessments through which the impact of using ConcepTests as an instructional measure may be assessed (e.g. Hake, 1998; Crouch & Mazur, 2001, etc). However, it was not feasible for me to adopt this measure due to research design constraints and limited resources. This is why I have adopted the qualitative, and hence subjective approach in characterising the EVS questions used in lectures. In the next section, I will present the analysis of the kind of impact that the EVS question types have had on student learning approaches.

---

[28] Data compiled from Carneson et al, 1996; Zimmaro, 2004.

6.4 IMPACT OF EVS QUESTIONS ON LEARNING APPROACH

As part of the interview protocol or schedule for the interview study introduced in Chapter Three, interviewees were asked to either solve or attempt to provide a solution to at least six of the EVS questions that had been used in class. These six questions consisted of the five question types identified above – there were two application type questions. But teasers were not represented because they were seldom used in class.

This section will highlight how a question type influences student approach. In particular, I will be illuminating how the question types described above tend to elicit specific approaches to learning at the *task* level. Further, the question types will be presented from the perspective of the type of learning *effect* they evince, based on the limited evidence from the interviews. It is quite probable that these question types evince other types of learning approaches or effects. However, I will be presenting only the learning effects I observed during the interviews.

6.4.1 CONCEPTUAL INTRODUCERS AND CONCEPTESTS

Introducers, as the name suggests, refer to a group of EVS questions which may be used to introduce a topic in class. There are two types of introducers, based on the purposes earlier highlighted. Direct Introducers are used simply to prepare a student for a topic. An example is the presentation of the equation of a straight line from a triangular wave to prepare students for the introduction of topics on Fourier Series (see section on Revisions).

In contrast, Conceptual Introducers are used to introduce a topic, such that it gets students thinking in a different way about a particular topic than they are accustomed to. For example, the purpose of Q1 (Figure 6.2), which was a conceptual introducer, was to get students to relate a double integral to its real world equivalent namely, volume under surface. The students generally did not have any difficulty doing the straightforward calculation, albeit in a procedural way, as shown by the following comments from three interviewees (i.e. K10, K7 and K3):

S: Why, why do you think it's 16?

K1: Um, well, it's 4y after you've done the first one for, um, between 3 and 1, so that's 8. And then it's between 2 and 4, which is, um, times it by 2 again, so that's 16…

S: Yeah.

K10: My natural procedure is just to integrate it

S: Ok. The question is without integrating, evaluate. Can you do that?

K3: Yeah, I think so.

S: What do you need to do?

K3: I just look at that and say... When I look at that, the answer, obviously, I've got the paper in front of me, the answer 16 just jumps straight out at me.

S: Why does it jump straight at you?

K3: Um, integrating between 2 and 4, one of three differences to be a 2, integrating 4 itself. Obviously it's probably not how I've said that.
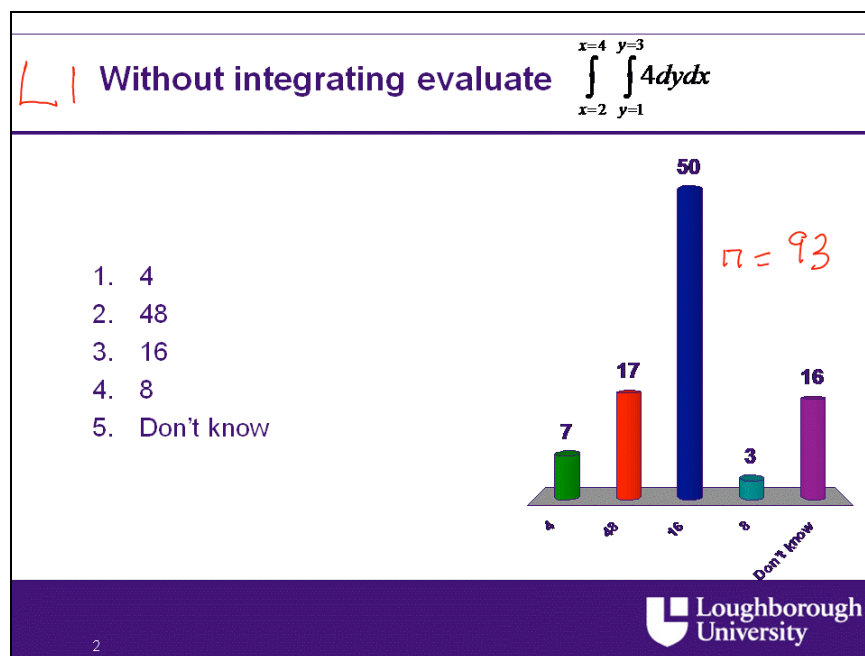
Figure 6.2 Q1 – An example of an Introducer-type question.

In essence, all the interviewees employed a procedural (surface) approach, which they were familiar with, to solve the problem. Meanwhile, the ability to solve the question depended on insight into the region of integration and interpretation of '4' as height of surface. Interviewees who could not visualise this boundary were subsequently unable to solve the problem as intended (e.g. K7):

The question says 'without integrating'.

Yeah.

Try to solve that problem.

I couldn't do that. I'd integrate it in my head.

In contrast, those who could visualise the boundaries of the integrals (e.g. interviewee - K3) were able to change their preference for solving the problem from algorithmic (procedural) approach to accommodate the visualisation strategy required to solve the problem:

First of all, what's the question asking you?

Um, find the area under that graph with, without using integration. So, just, like, I don't know. My natural procedure is just to integrate it, or whatever to do.

Why is that?

Because I think it's quite straight, I know how to do double differentiate, double integration, so I think it would be easier than trying to... It's the only way I could think of doing –

Than trying to do what?

It's imagining the graph and then –

So, you have to imagine this to be able to get it right?

Yeah. I think so. If I wasn't doing integration, I'd have to imagine what the graph would look like.
Visual representation [At the same time].
Yeah. And then –

Do you struggle with that?

A bit, yeah.

So it's easier for you to do the calculation than to do representation.

It depends, because if it was a single integration...

Yeah.

... just, like, the 2d thing, I think that'd be alright. But with these double differentials, I find it hard to visualise what that graph represents.

Yeah. Ok.

I, um...

When I asked K3, how s/he would go about solving the problem by utilising a more visual strategy, s/he responded that s/he would need writing materials, which I provided him/her with:

To help you to visualise, because you're more used to, most people are more used to working in 2d. What do you think should be done to help you to visualise this kind of problem, for instance, in 3d?

Um, we use the, um... If I had a piece of paper I could draw it, I think –

Yeah. That's what the piece of paper is for. The scrap. You can start from the...

I'd probably start off by just drawing a 2d out, just like that, [Unclear muttering by interviewee] so, it would look like a rectangle, like that, I think. And I think after I'd drawn that, I'd find it quite easy.

Ok.

I think, if that's right anyway, I think.

So, actually, to, if you couldn't do it like your normal approach to mathematics, you wouldn't be able to do this in your head. But if you are given paper and pen...

Yeah.

... and you start to draw...

Yeah.

... and put, put in the values you have...

Yeah.

... it's easy. You now start seeing how the shape comes together.

Yeah, exactly.

The main factor interviewees cited for the fixation on numerical strategies was previous teaching, which had conditioned them to automatically think of solving a calculus problem via algorithmic or symbolic manipulation, which is largely a procedural surface approach:

... the context of the lecture would sort of do that. Because you'll have been doing questions that haven't involved integration. You'll have been doing it from graphs and things.

Yeah.

In summary, it appears that conceptual introducers, based on evidence of how interviewees responded to Q1, might induce a deeper approach to learning in students. Perhaps, a frequent but judicious use of conceptual introducers could help stimulate students into an active consideration of other alternatives for solving problems, instead of the apparently obvious, usually algorithmic or procedural option. The use of these questions may help induce a more conceptual, flexible or holistic approach to problem solving in students.

CONCEPTESTS

An example of a ConcepTest is Q6 (Figure 6.3) and as one student (K5) pointed out, these were not regularly used in class:

Because, yeah, I remember the statement. We don't do too many of these things. And there aren't too many of questions that, you know, they just make you think rather than make you work out something.

Ok so you don't do many of these?

No, we don't do many of this sort.

Because you have to think through each statement...

That's it, yes.

...to see what's going on.

Yes.

By having to think through each statement before being able to arrive at the correct solution(s), it may be stated that the students are having to identify 'logical fallacies in reasoning' and/or 'evaluate the relevancy of data' (Carneson et al., 1996).
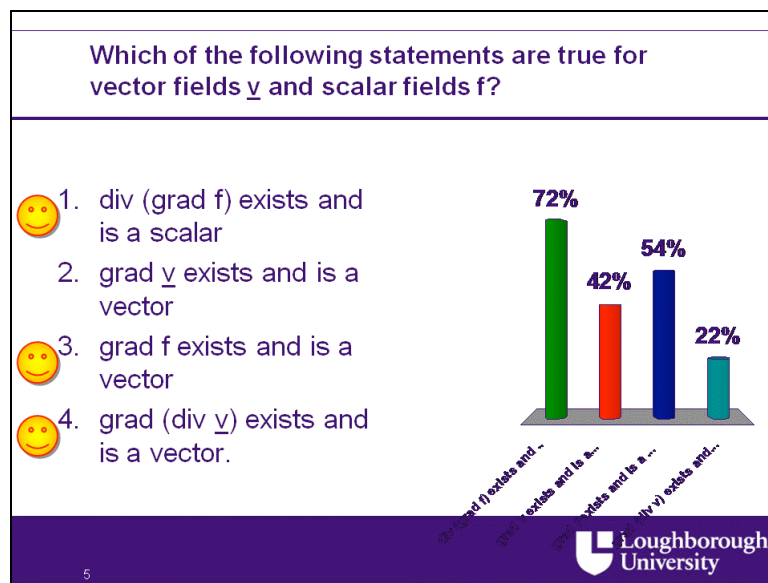
Figure 6.3 An example of a ConcepTest.

Research indicates that ConcepTests are invaluable for inducing a conceptual learning approach in students (e.g. Crouch & Mazur, 2001; Mazur, 1997; Hake, 1998; Russell, 2008; Lomen & Robinson, 2004). However, the module focus on problem solving meant that the use of ConcepTests was limited. But it should be pointed out that it is possible that perhaps a few students would still adopt a procedural (surface)

approach, irrespective of a particular task nature. For instance, one interviewee (K2) pointed out that some students might still resort to memorising the relevant statements instead of critically working through each to determine which of the statements met the criteria, based on understanding of differential vector calculus:

Yeah, if I knew at that time. Like I told you, when I practised for the test, for this topic, I just practised. I didn't pay attention to what I was doing. I was just doing it, 'cause I knew do it, I knew how to differentiate. I knew, 'ok, this is how you do it, and for the divergence you do this, for the gradϴ you do this' and that's it. So I didn't really pay attention to the concept.

You see, for this one, you need to understand what's happening before you can get it.

For this one?

For this one, yeah.

The one before? Or this one?

The one before, you said you could follow that.

Exactly. If you know how to differentiate then, exactly, you can do it. For this, you know how to, you should know –

You need to know what's happening before.

There are people, there are people and, um, who can just go into the, who can look into the workbook and say 'ok, it says'... I remember there was a statement –

A statement? So you had to memorise it?

Exactly. Some people do that.

So if you memorise it, then you don't really have to understand the concept?

Exactly.

In summary, ConcepTests, of which only one question has been presented in this section, are helpful in inducing a deep approach to problem solving.

6.4.2 DIRECT INTRODUCERS AND REVISIONS – ELIMINATION EFFECT

Some of the tasks that were set for the students to do often had dual roles as question types. For instance, Q3 (Figure 6.4) served as both an introducer and revision. It was a type of direct introducer because the question was administered in class prior to the teaching of Fourier Series because the lecturer wanted the students to become acquainted with working with the parameters of the formula for the equation of a

straight line as presented in the question, as this was the form in which the equation would be presented to them in Fourier Series. The task also served as a revision task, which is the way the question would be presented in this section, because solving the problem required knowledge of the equation of a straight line, which the students had not done since taking GSCE i.e. two or three years prior.
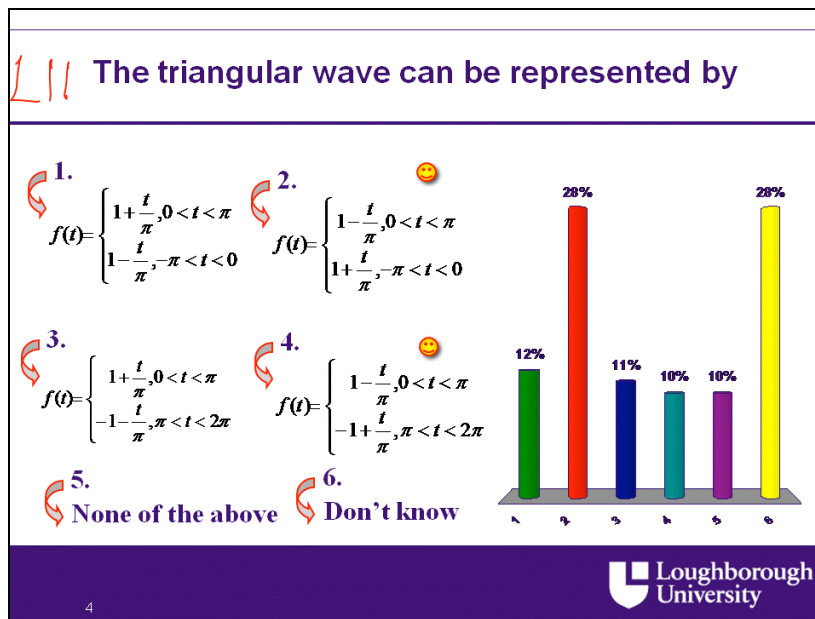
Figure 6.4 Q3 - An example of a revision-type question.

This particular question i.e. Q3 (Figure 6.4) induced an elimination strategy, and hence largely procedural (surface) approach, based on task characteristics and observation of how students attempted the task. This is because it is possible to deduce from the slope of the lines in the triangular wave, given (Figure 2.5) that options 1 and 3 are incorrect. Moreover, the interviewee recognised this as well. In fact, one of the interviewees referred to Q3 as 'one of those elimination questions':

Ok. Do you remember from the voting system questions or from the topic? What made you remember? This question – what made you remember? Do you understand – you say you remember this question, I'm just –

Yeah, yeah, yeah.

... trying to work out the link. Because sometimes, you –

I don't think I can say. It may be the fact of, that, I think this may be one of those elimination questions.

Another interviewee (K5) stated that the question was an 'obvious' choice for an elimination strategy:

Do you think this question is going to take some time?

No. No, it's number 2 I think.

Why would you say it was number 2? Why did you first say it was number 2?

Um... why? Because from 0 to pi I knew it's a negative gradient and from the other half of the period it's a positive gradient and I knew they would be pretty similar, so I'm trying to make a guess but I'm not doing a very good job. So I'd rather work it out properly. Like here, I wasted a lot of time trying to make a guess.

Wait, wait. When you see a question, a voting system question, you have the option of thinking about it or trying to eliminate the options. What do you do instinctively?

Um...

You try to eliminate the options?

If they are obvious, yes.

If they're obvious.

So, like on this one, it's really obvious it can't be number 1 or number 3 because it's a negative gradient between 0 and pi. That's why I said 2 or 4 and then...

Another example of 'those elimination questions' is a question on vector calculus (Figure 6.5) in which students could for example eliminate the scalar-based options i.e. options 2 and 4, as the answer would require a vector outcome.

L17 For $\phi(x,y,z) = x^2 z + xy - yz$, $grad\,\phi$ is

1. $2xz\,\underline{i} + x\,\underline{j} - y\,\underline{k}$

2. $2xz + x - y$

3. $(2xz + y)\underline{i} + (x - z)\underline{j} + (x^2 - y)\underline{k}$

4. $2xz + x - z + x^2$

5. Don't know

34%   4%   60%   0%   2%

Loughborough University

8
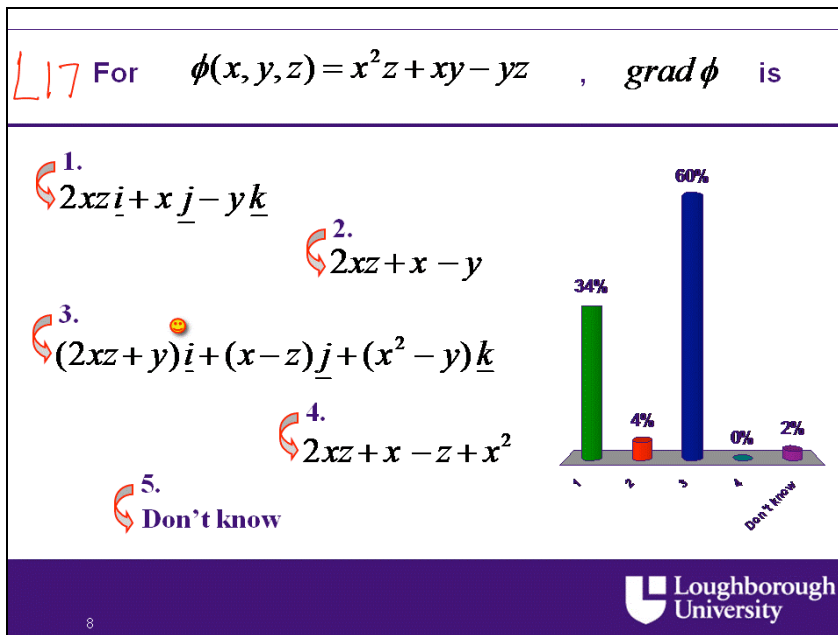
Figure 6.5 An EVS question on vector calculus which students often adopted an elimination strategy to answer.

However, it seemed that obtaining the correct answer via elimination might have been an indication of advancement in mathematical skills. One student (K10) commented that previously for a similar question, s/he would have first worked out the gradient and then used that knowledge to determine the right answer. But now s/he is able to determine, just by looking at the parameters given, whether the gradient is positive or negative, and from this eliminate or identify the option(s) that provide the best 'fit' for the problem:

With the equation of a straight line, for instance, what do you think about it? Application of the equation of a straight line to this problem? Would it apply?

I don't think, um, I don't think I think about it like I used to, like, before, like, a few years ago, I would have looked at that and had to work out the gradient.

Yeah.

I would have worked out the gradient by using, like, 0 to pi and, like, we were always taught to, rise over tread, so, like, the amount it drops by divided the amount equal across.

Yeah.

But nowadays, I just look at that and, I don't know why, but I just automatically think, and not really work it out, but just, 'cause you know it's, you don't really have to work out what the gradient is, you just have to know if it's positive or negative.

Yeah.

267

So I didn't really work it out in the sense that I would have, and just looked to see if it was positive or negative.

Ok.

I didn't really give it much more thought...

Ok.

.. than that.

In summary, when direct introducers and revisions are structured such that the questions are susceptible to being answered by an elimination strategy, a largely procedural surface approach to problem solving is induced.

6.4.3 APPLICATIONS

A numerical count of the questions used in class, which was undertaken by going through the lecture notes, showed that most of the questions that were used mainly fell into the applications category. The type of learning approach induced by application tasks, which by definition are used to assess student understanding of recently covered material, would largely depend on the course context. So a course that is focused on problem solving, such as the module being investigated, would generally have a preponderance of tasks where students are required to solve problems. Moreover, problem solving in this context would require the use of procedures. Hence it could be expected that application tasks would elicit a largely procedural approach, with varying degrees of conceptual approach, depending on task design and individual students. Questions Q2 (Figure 6.6); Q4 (Figure 6.7); and Q5a (Figure 6.10) are examples of applications.
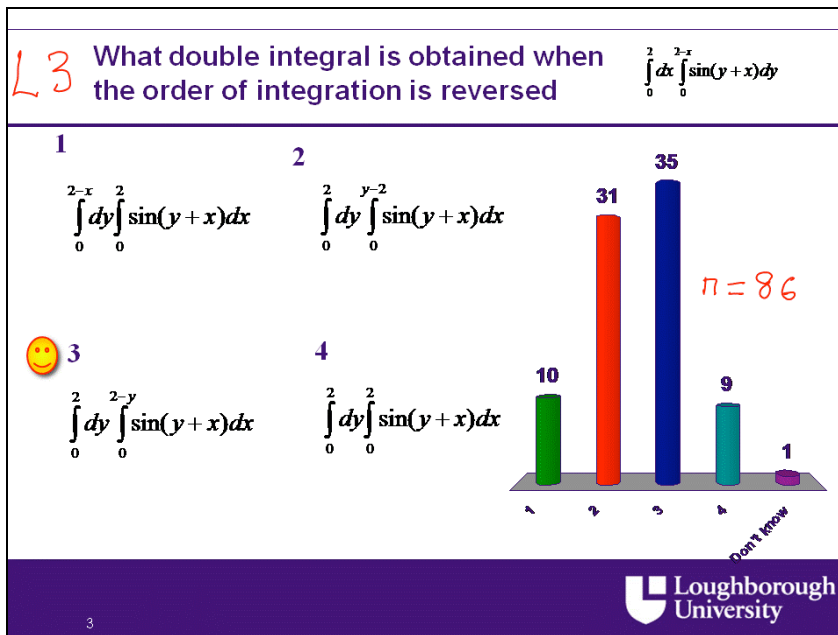
Figure 6.6 Q2 – An example of an Application-type question.

To solve Q2 (Figure 6.6) for instance, an interviewee (K4) simply identified the three elements of the task that s/he needed to manipulate to get the correct answer:

This is the next question. And, um, you were saying, it's something you don't like. Let's see. Do you recall this question? Do you remember?

I remember how she explained it...

Ok.

... like, the way to go through it. Like, I didn't get it at all and she like showed you how. It's just three simple steps, and it's like, you don't have to work anything out. It's just...

So, it's like that one to you, you don't have to work this out really?

No.

Ok. Which three steps do you think you need to do here, to take?

You put a variable in at equal to the other variables. So that would go equal to y, 2 – x, and then you would swap dx and dy over and you would change... sorry... you would change that, the other limit.

Ok. So you don't have a problem with that?

No.

So, you didn't get the question the first time, but when she provided a solution you could see –

269

This was largely a procedural surface approach as there was no intention to understand the reason why the limits were swapped the way they were. So if any of the elements of the task were significantly changed, the student may struggle at finding the right solution.

To answer Q4 (Figure 6.7), interviewees needed to be able to recall the sine wave correctly. However, a significant number got around this by plugging in values into their calculator via a trial and error method. But it was apparent that the students who adopted this approach had limited understanding of the concept. Comments from K1 illustrate this:

Um, this was probably one thing that I didn't quite get at first.

Ok. Why didn't you get it? What were you struggling with?

Um, just remembering which one's which. So I'd probably be tempted to try and use a calculator for it.
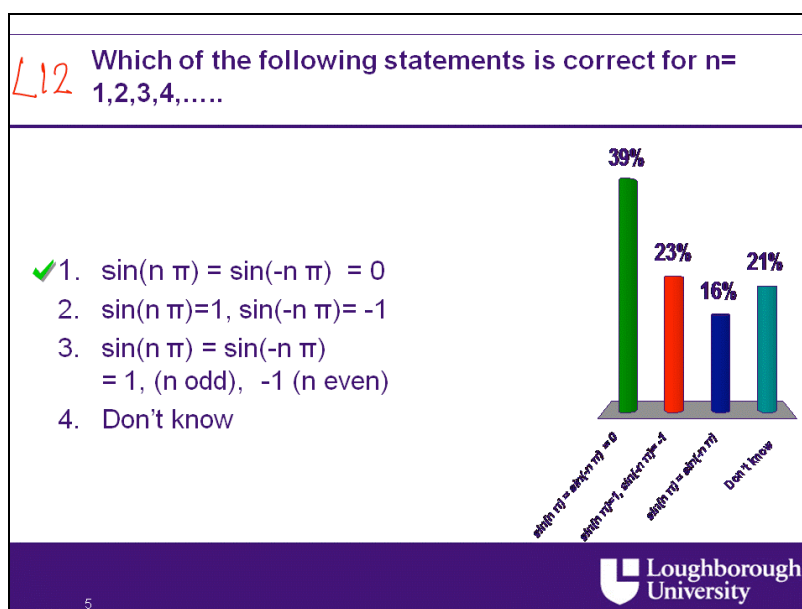
Figure 6.7 Q4 – An example of an Application-type question.

270

In contrast, the students who were able to answer Q4 without using a calculator seemed to show greater understanding. For instance, K10 commented that s/he mentally visualised the sine wave when s/he saw the question (so Q4 could be stated as inducing a procedural deep approach in this student because obtaining the solution required some level of understanding of the concept being assessed):

Yeah, I'm just... I think it's number 1, but –

Why is it number 1?

No, I think it's number 1.

Ok. Number 1. So, suppose you couldn't capture the image of the sine wave in your head...

Yeah.

... would you be able to answer this question?

I don't think I would, because I, I need to prove which, I use, I, as soon as that question came up I thought of the sine wave in my head and –

This one, right?

Yeah.

But someone, if someone doesn't remember this or they've forgotten or they, for somehow...

Yeah.

... do you think they can get the answer?

I don't think I would be able to get the answer without knowing that graph, no.

So, you were saying to get this question, it's easy, you need to be able to visualise the graph, the sine wave graph.

Yeah. That's right.

In essence, presenting Q4 with the requirement that a calculator cannot be used would likely induce a procedural deep approach to solving the problem.

Student approaches to solving Q5a (Figure 6.10) generally indicated that the question seemed to have elicited a largely procedural surface approach, as the basic technique was to memorise which differentiation method to apply to which vector calculus type of question. K7 and K8 exemplify this. In the first extract, K7 talked about how s/he could 'eliminate options' before 'even attempt[ing] the question':

271

So you said this in your last comment, in your previous comment, that you need to read the question and also look at the options to see what tallies.

Yeah.

Maybe look at it to see if there's a few pointers that that might be the correct option.

In some of them, in the later topics, where you had to answer, like, a div, grad or curl...

Mm hm.

... you kind of, if you understand what you're looking for, you can eliminate options before you even attempt the question.

Similarly, K8 submitted that a memorisation strategy that is devoid of an intention to understand could be applied to solving the type of problem represented by Q5a:

Um, I remembered there were three types ...

Yeah.

... in one, you differentiate all of them...

Yeah.

... with respect to, to one particular, um, variable.

Yeah.

Yeah. And then, one of them isn't a vector. Which is divergence I think. Yeah, divergence, I think it's not a vector. And gradient, um, grad...

Yeah.

... and curl are vectors.

Ok.

So it has to be a vector, it can't be 2 or 4.

Ok.

That it's a vector, first of all, so it can't be 2 and 4.

Yeah.

And out of 1 and 3, there's, there are two types. If it was divergence, then it would have been 1. [Incorrect]

Ok.

Because then you do it just once. You take the first term and then just differentiate it with x second term, differentiate it with y, third term, differentiate it with z.

Yeah.

So, you just need to know what grad, and, um, what divergence is and –

Do you need to understand this or you can memorise it?

I think you can memorise this. You don't need to understand it.

In essence, it might be conjectured that if the structure of a question (e.g. the options provided) makes obtaining the answer to it open to the adoption of an elimination strategy, or the use of a memorisation technique that is devoid of understanding, the question would typically induce a procedural surface approach in a large number of students. For consistency purposes, all questions with structural characteristics highlighted above are described as inducing a procedural (surface) approach to learning. However, this does not mean that the same question might not induce, for example a procedural deep approach in some students.

In summary, applications, as used within the engineering mathematics module being investigated, may induce a procedural (surface or deep) approach due to the focus on problem solving.

6.4.4 REPEATERS

As has been stated earlier, tasks set in a particular lecture and for which the percentage of correct responses was judged to be low, were often repeated in a slightly modified form either in the same class, or more typically in later classes. The purpose was to assess whether any significant improvement in student knowledge about the topic had occurred between the time the task was initially given (with correspondent instructor feedback), and the time the repeater question was given.

Examples of repeaters include Q4a – 39% of the class got the question right when it was first presented in the 12th lecture i.e. L12 in Figure 6.8 for the module, and Q4b which was set in the next lecture – the 13th lecture for the module (Figure 6.9), with the results showing a 24% increase in the number of students who were able to get the correct answer. Another example of repeaters are Q5a and Q5b (Figures 6.10 and

6.11), spaced one lecture apart, and with the spread in Q5b showing a 21% increase in the number of students obtaining the correct answer.

Figure 6.8 Q4a – An example of an application-type question that was later *repeated*.
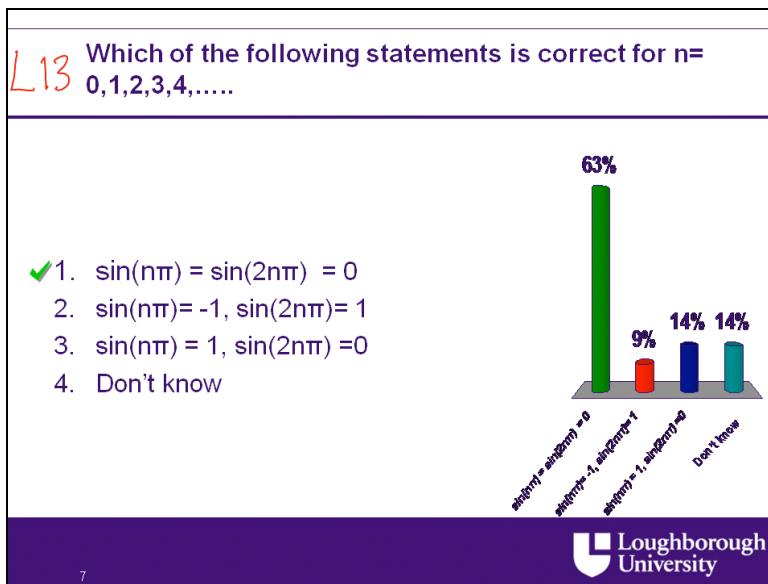
Figure 6.9 Q4b – An example of a repeater-type question.
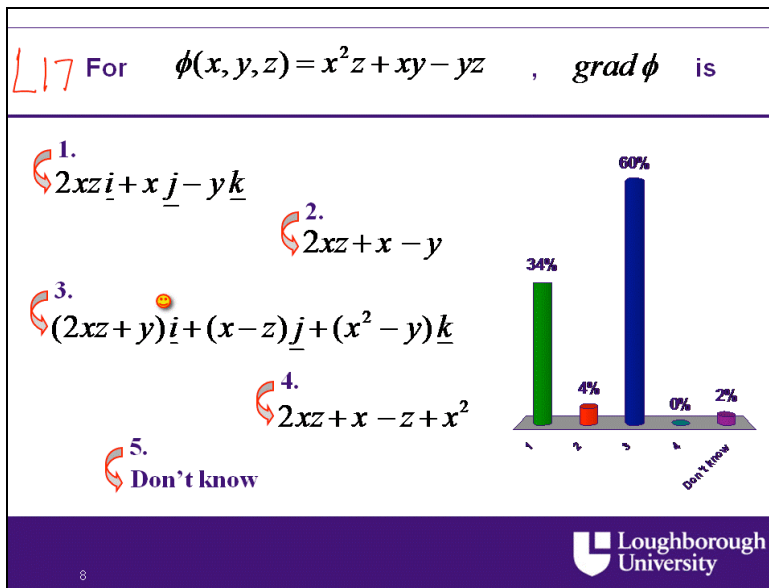
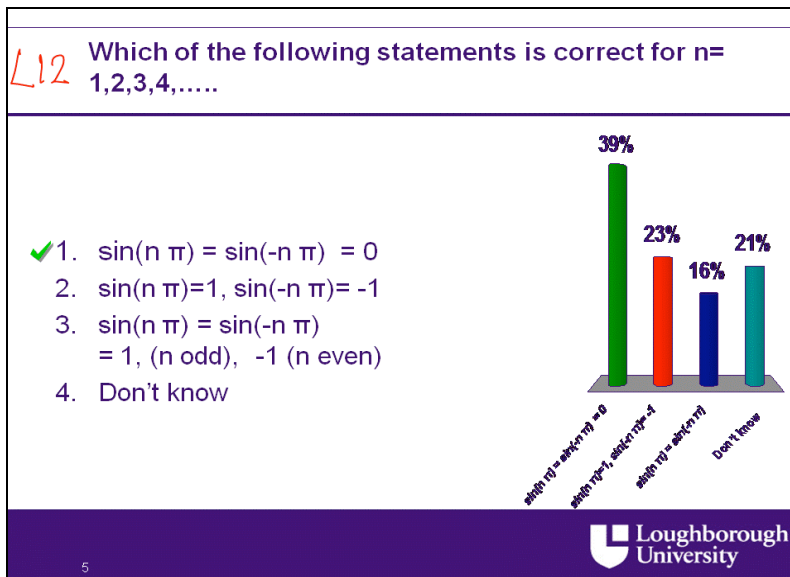Figure 6.10 Q5a – An example of an application-type question that was later *repeated*.
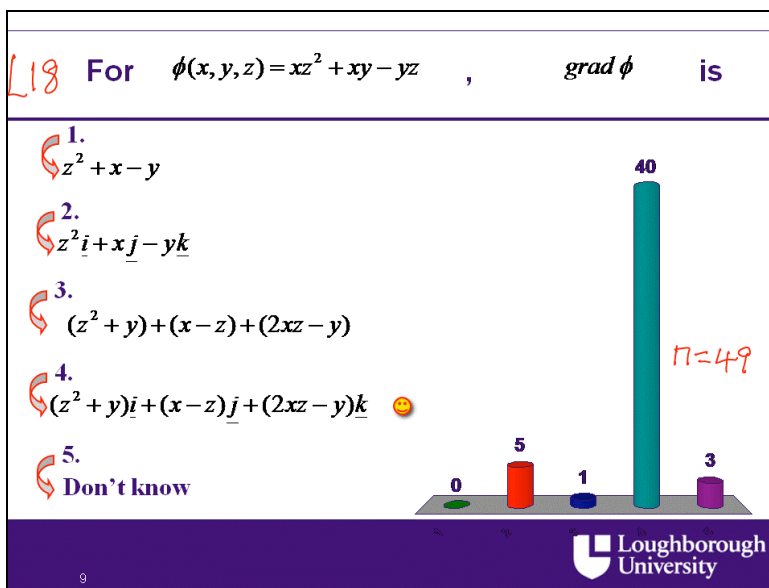
Figure 6.11 Q5b – Another example of a repeater-type question.

In summary, the type of learning approach induced by a repeater depends on which question type the original question is a subset of e.g. a revision or application question, when re-introduced as a repeater would probably elicit a procedural approach to problem solving.

6.4.5 SUMMARY

In summary, revisions and applications, as used within the context of the module, and based on one instructor's practice, tend to elicit a more procedural (surface or deep) approach to learning. In contrast, ConcepTests and conceptual introducers, because they stretch or challenge students' thinking about a topic, tend to elicit a more conceptual approach to learning. Repeaters could fall in either the procedural or conceptual category, depending on what question type the original question was (Table 6.3).

QUESTION TYPE	LEARNING APPROACH INDUCED
Conceptual Introducers and ConcepTests	Procedural Deep or Conceptual Deep
Direct Introducers and Revisions	Procedural Surface
Applications	Procedural (Surface or Deep)
Repeaters	Depends on original question

Table 6.3 The learning approaches induced by the use of specific EVS question types.

6.5 CALCULATOR USE AND LEARNING APPROACH

The ideal or intended use of graphical calculators is that by aiding the students in the performance of repetitive computational processes, students may be 'freed to focus on strategies' and to 'analyse and reflect on the relationships between data':

'Using the technology to carry out the manual labour of computations or drawing, frees the student to focus on strategies, and encourages a process of trial and error'   *(Becta, 2003)*
'Technology speeds up the graphing process, freeing pupils to analyse and reflect on the relationships between data'   *(Hennessy et al, 2001)*

This means that a judicious use of calculators should encourage a procedural deep or conceptual approach to learning. In fact, there is 'evidence that calculators can help as a bridge between teaching and learning mathematics with young children (Perks, 1995); that access to graphics calculators helped female students 'to develop a strong visual representation of functions given in their algebraic form (Smart, 1995) and to 'construct

their own mathematical understanding through conscious reflection' (Shoaf-Grubbs, 1995).

However, interviewee attempts at answering Q4 prompted me to question the veracity of the postulation that calculator usage frees students from number or symbol processing minutiae, so they could focus more on conceptual understanding. It appears that some students are using calculators for computational processes, and in the process, are entirely neglecting to think about the concepts underlying those processes. K1 for instance might have viewed calculator use as a way of circumventing the need to understand a problem:

Um, this was probably one thing that I didn't quite get at first.

Ok. Why didn't you get it? What were you struggling with?

Um, just remembering which one's which. So I'd probably be tempted to try and use a calculator for it.

Another instance is K4 who, when s/he could not recall the knowledge required to solve Q4, simply resorted to using a calculator as the alternative way out. His/her reasoning seemed to indicate that s/he thought s/he could substitute the requirement to understand a problem with the computational power of a calculator:

To get this question, do you have to do something? Or what, what would you have to do?

I'm sure some people could just do it in their head – like, really logical people. But I would probably have to sit and work it out.

Suppose you wanted to sit and work it out, how would you do it? Now?

Yeah, I would –

I mean, I'm saying, try to do it.

Oh god. Ok. Try and remember my rules. Sine... [unclear muttering by interviewee] I'd probably need a calculator. I'm sure there's some easy way to work it out.

K9 is another student who, in addition to using the calculator for laborious computations for speedier mathematical processing, also sees the tool as a device for working on problems s/he has difficulties with, such as Fourier Series:

I wouldn't, I wouldn't know how to do this one unless I had a calculator.

So, if you had a calculator, you would just use a calculator.

Yeah.

What kind of questions do you use a calculator for?

Um, trig stuff.

Because you don't like trig stuff?

Yeah. I can't do trig.

Ok. And, trig, does any other question come to mind, or topic, or area...

Um –

... where you used a calculator?

Fourier series, I did. Sort of if it was A1 +B1 +, you know, you have to add it all up. It's just a lot, if you want to get the answer before she gives it to you, it's a lot easier just to put it all in.

Yeah.

Um...

So you do that sometimes before she gives you the answer? You can put it all in and get the answer?

Yeah.

But does that tell you how to do it? I mean –

No, but if you work out the formula...

Yeah.

... and you've got, you know, A1, A2, A3, A4, and something was 'add them all together'...

Yeah.

... I'd do it on the calculator 'cause then you get the answer quicker.

As K5 points out below (K5 is one of the students diagnosed as displaying a conceptual deep approach), instead of being able to accurately represent or visualise a sine wave, a simple concept they had been introduced to at GCSE level, some students instead resorted to a trial and error method by entering values into a calculator to determine which of the options provided for Q2 was the correct one:

Yeah. If you ask... in my course if you ask most people, if you ask them to evaluate sine and pi they'd use a calculator.

278

Why do you think that? Why do you think that happens?

Because in A levels or whatever they were shown how to draw that, they probably did it using a calculator.

So you think that's the problem? So with this question in C's class, many students would have just got out their calculators to find out the answer to this?

I don't think even that because I remember her once saying 'just replace n with a few values', like do n equals to 1 and then n equals to 2 and see what you find. And I could see people using calculators.

For this kind of question? In C's class?

For this kind of calculation.

Where? Which class?

C's class.

So you think that's the wrong thing to do?

Yes.

That's the way they were taught, at lower levels.

It's very simple, I was never allowed a calculator, so it's different for me.

K3 illustrates an ideal approach to using a calculator - to verify the outcome of a computational process about which a student has considerable mathematical knowledge:

If you didn't visualise what was happening with the wave...

Mm.

... a diagram – do you still think you could get this answer? Is that possible?

Um, obviously you've got to plug the values into a calculator.

Yeah.

And that would give you them all. But that wouldn't be satisfactory to me because I haven't... even now I still have to remember it was a repeated function and I would still have to remember. 'Cause no matter how many values you put into a calculator, you're never 100% sure if it's going to be right.

Yeah. You could make a mistake if you don't get the functions right.

279

Mm. I suppose it's the whole, like, it proves you can't just, you can't exhaust it. You can't be sure it's 100% true unless you know the fact that it is a repeated function.

It might be argued that the level of challenge of the subject might have induced K1's approach. But a peer (K3) points out that solving a problem of that nature should not have been a difficulty:

Yeah. Sine of any pi is always 0.

Yeah.

I think it's like number 1 but I'm looking again to see if it's got... It's definitely not number 2. It's definitely not number 2. It's definitely 1, it's definitely 1.

So why do you think, where do you think someone might have a problem with this?

Um, underst... I don't see any actual reason as to why there would be a problem. Um, if you're told, you're told not to use a calculator, you may not know how to visualise a sine wave.

Did you visualise the sine wave? Before I gave you the –

Yeah. I think that with sine, cos, even when I'm integrating and differentiating sine and cos, I draw down the sine graph and then think 'the gradient at the first point is 1, so then the gradients 0, so you go to 0'. Then I realise it's going like that and think 'that's a cos'. And for the cos one I just look at the gradient on each point...

Yeah.

... to get my mind of sine, and obviously let it –

You always do that? You always do that?

Pretty much every single time I've got to integrate sine or cos.

Ok. Some people got it wrong. Are you – What do you think? Why do you think they would get it wrong? They forgot or something?

I don't know. Why would people get that wrong? Um, possibly forgotten the period of which sine runs over.

And this question was A level. It's not your level? It's not your level?

I wouldn't even say that's A level.

It's GCSE?

Yeah, I'd say it's more GCSE, 'cause you've got to know sine for your GCSE.

6.5.1 SUMMARY

Based on the (limited) evidence about the largely procedural use of calculators as a substitute for mathematical thinking, there might be a need to rethink how and when calculators may be used in mathematics classes. This is imperative so that the habitual use of calculators does not replace or erode basic or fundamental mathematical skills. Calculators provide optimum aid for mathematical learning when they 'release us from the drudgery of acquiring speed and accuracy in doing complicated calculations. They do not release us from the task of knowing what are the appropriate calculations to do, or whether the answer makes sense. But they make more time available for learning with the emphasis on understanding, and thereby help us to meet this obligation' (Skemp, 1989, p169).

However, it appears that some students view the calculator as a way of bypassing the need for understanding or automacity development. These students probably see the calculator as a tool to use i.e. they are *mathematical users* instead of a device to learn mathematics with i.e. as *mathematical learners* (Hoyles & Noss, 2003). It is interesting to note that the students (highlighted above) who demonstrated a purely computational or procedural surface approach to using calculators (e.g. K1, K4 and K9) were diagnosed earlier as having limited ability in employing visualisation strategies.

Further research needs to be undertaken regarding the role that calculators play in enhancing student mathematical thinking skills, as opposed to their use for computational processing. This is pertinent as a recent study on mathematics teaching and learning (NMAP, 2008), whose conclusions about the role of calculators in mathematics learning I only became aware of after the conclusion of this study, arrived at the same conclusions reported in this section i.e. that they 'found limited or no impact of calculators on calculation skills, problem solving, or conceptual development over periods of up to one year':

A review of 11 studies that met the Panel's rigorous criteria (only one study less than 20 years old) found limited or no impact of calculators on calculation skills, problem solving, or conceptual development over periods of up to one year. This finding is limited to the effect of calculators as used in the 11 studies. However, the Panel's survey of the nation's algebra teachers indicated that the use of calculators in prior grades was one of their concerns. The Panel cautions that to the degree that calculators impede the development of automaticity, fluency in computation will be adversely affected. The Panel recommends that high-quality research on particular uses of calculators be pursued, including both their short- and long-term effects on computation, problem solving, and conceptual understanding. *(p24)*

6.6 GUESSWORK AND LEARNING APPROACH

Multiple-choice questions, which are the main instruments for enabling formative instruction with EVS, have two main drawbacks. First, there is research to suggest that the use of MCQs tends to promote shallow learning i.e. surface or procedural surface approach to learning, or as Draper (2009) describes it:

'Here shallow learning is characterised by retention of true–false items that are either disconnected or linked in just one way for one use, while deep learning is characterised by learning multiple relationships between items that can support multiple uses (i.e., transfer tasks) better'   *(p287)*

However, it has been shown that a careful attention to the design and use of specific question types can encourage a deeper approach to learning in students (e.g. Draper, 2009; Beatty et al., 2006).

The second major drawback is the student habit of adopting a guesswork approach to answering MCQs, so it becomes more challenging to ascertain what students really know. Guesswork is therefore or usually viewed from a negative perspective. To overcome this barrier – to essentially discourage guesswork, almost all the EVS questions in the mathematics module under focus had an 'I don't know' option.

In this section, I will show that the adoption of guesswork is not always counterproductive. This will be done by presenting the types of guesswork identified from interviewee attempts at answering the EVS questions posed during the interviews. I will then present the relationships between guesswork type and associated learning and/or problem solving approaches.

6.6.1 TYPES OF GUESSWORK

The three types of guesswork that were identified during the interview process, based on student attempts at solving problems, are:

1. Educated (Coherent) Guesswork: This is guesswork that is defined by a largely coherent structure or approach to solving a problem. Students who adopted this strategy usually had some level of coherent or constructive knowledge about how to solve a particular problem. The adoption of this strategy is in most cases tantamount to

a procedural approach. An example of an educated guess approach is the use of elimination for obtaining answers to questions (see Section 6.4.2).

2. Exploratory (Incoherent) Guesswork: This is when a coherent or constructive pattern for solving a problem is not immediately or initially available to a student. But instead of selecting the I don't know option or merely waiting for the instructor to provide feedback on how to solve the problem, a student attempts to answer the question by starting out with the 'knowns' (drawn from students' general mathematical knowledge base or 'example space e.g. Antonini, 2006; Dahlberg & Housman, 1997; Zaslavsky, 1995; Watson & Mason, 2002) and working his or her way to the 'unknowns'.

3. Lottery (Wild) Guesswork: This is the outcome when a student has no clue about the procedures or steps to follow for solving a problem, and any answer provided is based on a completely random choice, without any rational or cognitive basis for the choice. This type of guesswork has no discernible educational value.

From the interview data, two groups of students were identified based on their selection (or otherwise) of the 'I don't know' (IDN) option and associated use of guesswork:

- Group 1: Those who usually select IDN when they do not know the answer to a question, and who when they guess, employ only educated guesswork
- Group 2: Those who prefer not to select IDN when they do not know the answer to a question, and instead employ both educated and exploratory guesswork

It would appear that Group 1 students are 'model' students (see Table 6.4 for a classification of the interviewees) because they refrain from employing guesswork in solving mathematical problems, and that their peers in Group 2 could be encouraged to adopt their approach.

However, the use of guesswork by students in Group 2 was by no means uniform, as the guesswork employed by these students consisted of three distinct types, as described above.

GROUP 1	GROUP 2
K1, K2, K3, K6, K8	K4, K5, K7, K9, K10

Table 6.4 Classification of interviewees based on adoption of guesswork.

6.6.2 GROUP 1: IDN-SELECTING GROUP

This refers to the group of interviewees who usually select IDN and do not guess. K1 and K8 are examples of students who belong in Group 1 as exemplified by the following comments from the two students, in consecutive order:

No.

Ok, do you always, when you answer, do you always know the answer to the question, or you guess sometimes?

Um, if, if I know it's, if I know it's between one of two answers, I'll guess...

Ok.

... out of one. But otherwise I normally put 'I don't know'.

•••

You won't wait for, some people have said they don't click, they don't want to put 'I don't know' because... What do you think about, the 'I don't know', if you click 'I don't know', how does that make you feel?

I, I think it's important, because the lecturer should know if people don't know. If, suppose she gives a question...

Yeah.

... and nobody has a real clue of what's happening...

Yeah.

... it's better that all 100% vote for 'don't know'...

Yeah.

... so that she can again explain it, you know? Rather than 25% all voting for 1, 25 for 2, 25 for 3 and 25 for 4.

Yeah.

That would make the lecturer think that they probably had some clue, you know, about it.

284

And they don't.

Yeah. When they actually don't.

It is pertinent to note that some of the students in Group 1 do not always select IDN. K6, for example sometimes simply refrains from voting and waits instead for the lecturer to go through the solution. But the main difference between students in Groups 1 and 2 is that students in the former group do not usually employ exploratory guesswork, although they sometimes make educated guesses. K6 for instance says that s/he only selected IDN in about one out of every two instances where the option was available:

So, you've experienced, your observation is that there are times when not many people answered.

Yeah. But you can tell that, well, you can't. It's quite obvious that people didn't answer because they didn't understand.

Ok.

Not just because they couldn't be bothered. Because every other lecture, every other question, everyone will answer. There will be the odd occasion where 20 people out of the 100 people there will answer and she'll go back over the question and why it was that. That's really handy.

Based on your observation, when people don't answer, is it a case of 'I can't be bothered' or 'I don't understand'?

It's generally 'I don't understand'.

Ok. Generally. So if they could all understand the question, they would try or attempt to answer it?

Yeah.

Ok. What about 'I don't understand'? There is an option of, sometimes C puts 'I don't know'.

Yeah.

So why don't those guys, why don't they, I mean, why can't they just vote 'I don't know'?

Um, they, well, half of them do, and half of them just think –

What's happened? Because 'I don't know' kind of sends the message 'I'm stupid'?

Um, I don't know really. Um, I think if you don't understand at all you might just leave the controller well alone and still be trying to work it out…

Yeah.

… or work out where you've gone wrong.

Yeah.

And then the voting will be cut off and you're still trying to work it out.

Ok. That's a different scenario, when you're actually trying the question…

Yeah….

Have there been times where you've found a question too hard?

Um, there have been but that's usually because I've not understood it first time round. But I'll understand it the second time round.

Yeah. What did you do – did you vote 'I don't know', did you abstain from voting?

I think it's been 50/50. Sometimes I just haven't voted and sometimes I've gone for 'I don't know'. I don't know why I don't press 'I don't know' when I don't know all the time.

6.6.3 GROUP 2: NON-IDN GROUP

This refers to the group of interviewees who prefer not to select IDN, and instead employ both educated and exploratory guesswork. K5 is an example of a student in Group 2 and who in his/her words, always 'try and work it out' and in addition, is of the opinion that those who selected the IDN option, within the context of an EVS lecture, were either disengaged or simply too lazy:

What about times when you can't... when you don't know the answer? You don't know the answer to a question and there's an option you don't know. Do you make a guess?

I don't make a guess.

You don't make a guess.

No.

Why not?

Um, because mathematics is not about guessing, is it?

So if you don't know, that's an 'I don't know' option?

There is an 'I don't know option'.

You'll click 'I don't know'? Have you done that? Because there have been a few questions where she put a question and that was an 'I don't know' option or 'none of the above'.

I never put 'I don't know'. I try and work it out. And if I don't get to an answer and she stops the voting, then...I always try to find out an answer.

Ok.

I always try to attempt.

And...

Sorry.

It's alright. We have to look at different scenarios, so...

I know people who do use 'I don't know', but they sit there and they don't concentrate in the lectures, so they don't know what's happened in the last half an hour. And then the question comes up, they don't even try and press 'I don't know'. I don't see the point, you wasted an hour of your life like that.

That's good. So, for you, you think you should at least try and make a guess even if you don't know.

Yes. You should try.

Try and eliminate the options.

Yes, sometimes it's possible to eliminate.

And sometimes not, so just go for it?

You just try and have an answer.

Apart from not considering educated guesses as a type of guesswork because of the level of mental engagement and subject-specific knowledge required, K5 also asserted that those who selected IDN were those who 'couldn't be bothered to think':

Are you surprised at that, not, I mean 50 out of 93, that's less than 50%.

That's 50 out of 93?

That's under 60% of the class got it. What do you think about the spread?

The 16 people said 'I don't know' are people that couldn't be bothered to think. Because I know, I'm just talking by experience...

Yeah.

... I see people around me do it. I don't know – they don't even try.

They can't be bothered.

Can't be bothered.

So you think 'I don't know'... many people, many students would go for 'I don't know' when they can't be bothered, ...

Yes.

... or when they weren't paying attention?

Yes.

Does it make sense to include 'I don't know' as one of the options?

If it helps the lecturer then maybe. I'd rather, I suppose, have people say 'I don't know' than just guess an answer.

Why not?

Because, if they, if they guess without intelligence, if they just make a pure guess...

Yeah.

... you don't know whether you're delivering well or not. If they say 'I don't know', at least –

So you see it from the lecturer's perspective as good? But not necessarily for the students because...

Not for me, it doesn't help me in any way.

Similarly, K9 submitted that s/he did not select IDN because s/he did not see the usefulness of adopting that approach from a learning perspective, although s/he conceded that selecting the option might have provided a more accurate feedback about the level of student understanding to an instructor:

But sometimes the instructor puts up the 'I don't know' option. Do you click that?

Normally, I try and make a guess even if I know that I haven't got a clue.

Yeah.

Because that way I know if I'm in the right field or whether I was completely out. Whereas if I put 'I don't know', then I don't know which of those four answers I would have chosen, had I, you know, needed to guess, sort of thing.

Yeah.

…I don't think that the 'I don't know' answer helps me by clicking that.

Yeah.

It might, it might help her...

Yeah.

... because then she'll know how many people really haven't got a clue.

Yeah.

But for me, if I clicked that, then I probably wouldn't think about the question. Whereas if I, if I don't know, at least I can try and make a decision.

Yeah.

I mean, sometimes I won't click anything, but most of the time I'd rather think about it and think 'oh, it might be B' rather than clicking 'I don't know'.

Yeah.

'Cause at least that way, I've thought about it.

K4 employed exploratory guesswork because s/he did not view the selection of IDN as being 'very helpful' for him/ her. However, his/her preference for attempting every question seemed partly influenced by the correlation of selecting IDN with 'failure'. Further, K4 was the only one who admitted to making a wild guess:

Suppose they [i.e. the EVS questions] have an 'I don't know' option – do you go for that instead of guessing?

No. I don't think 'I don't know' is very helpful on it. Like, not if you know anything. But I guess it is, 'cause, like, it shows her who, if, like, people actually don't know. And it would probably make her more likely to go through a question if lots of people don't know.

No, I don't want you to talk from C's viewpoint now. What you would do if you see an 'I don't know' and you think you can make a guess, you could make an educated guess –

I would probably guess.

So you would rather guess...

Yeah.

... instead of picking 'I don't know'.

Yeah.

What does 'I don't know' mean – does it mean, like, you're stupid or –

It's a bit like a kind of, I don't know, failure. It's a bit like 'I can do this – why would I just pick this?'.

Suppose there's some very hard question where you don't have a clue whatsoever. Would you still make an educated guess or just a stab in the dark instead of choosing 'I don't know' if you have an 'I don't know' option.

I'd take a guess.

You'd take a guess. Ok.

I don't know if that's helpful to her learning, like, her using the system at all –

It doesn't matter whether it's helpful, I just want to see what you would do. And that's what I'm concerned about here. Ok, you'd take a guess, ok.

Yeah, I'd probably take a guess.

K7, another Group 2 student, stated that his/her reason for employing guesswork was partly because s/he did not like admitting s/he could not do something, and that selecting IDN might have connoted stupidity, although s/he also conceded that selecting IDN might have been helpful for the instructor:

Yeah. What about if you, you see a question and you can tell from looking at the question you don't know what to do?

I give it a go, even if it's, 'cause we do have the option to say 'I don't know'. But I'll give it a go and try and not write notes. But sometimes if you don't know how to do it, you haven't got time to go through all your notes to do it.

Yeah.

But I do.

Ok. So you always attempt.

Yes.

You don't like, you don't like selecting the 'I don't know' option.

No I don't. I'd rather, even if it's an educated guess, I don't like guessing unless it's educated, because, especially as C does use it quite often to see how we are doing and to see what we need to put more work into in class...

Yeah.

... um, I think if you luckily guess the right answer and you don't know it, it could affect that if many people have done it. And she might think 'oh, the class knows what they're doing' and we've guessed it. So I try not to guess if I can help it.

Ok. But the 'I don't know' option is not something you would go with? Why?

290

I've pressed it a few times when I really can't do it, I really don't know. But I try and... I don't like admitting that I can't do something; I like to just keep working at it.

Does that make someone feel stupid saying 'I don't know', like a vacuum, you don't know what you're doing?

Yeah.

Ok. What do you feel when... When a question is hard, what do you do, I mean, you try to work it out anyway?

Yes.

Even if it's hard?

Yes.

.

K10 is an example of a student who sometimes employed both educated and exploratory guesswork and sometimes did not, subject to his/her mood. Note that his/her preference for making a guess when s/he is in a good mood, and thus more likely to be engaged with learning, is further evidence in support of the relationship between exploratory guesswork and student engagement with learning. In the first portion of the extract, K10 said s/he would sometimes guess when confronted with 'hard' questions:

Ok. And if you... I'm trying to think of that one. You said if the question's too hard for you, you'll make a guess.

Yeah.

So, that means, you know, there are two types of question that would come into that category. There's the question where it's hard – you don't know, it might be between A and B, or C and D, so you just think 'I think C...

Yeah.

... it seems the more likely answer', so you click C.

Yeah.

Then there's another category where you have absolutely no clue. Maybe you've not done it before, or you've forgotten what it's about...

Yeah.

... so you just go a stab in the dark.

Yeah.

Which one does your guesswork fall into most of the time? I probably think you've done both.

A stab in the dark, it's just –

A stab in the dark.

But also, you often have, um, an 'I don't know' option.

Yeah.

So you can press that if you don't know the answer.

But you don't press that, do you?

I do most of the time, but then occasionally you just think 'oh, what the hell, I'll just have a guess'.

So you, once in a while, once in a while, you just say 'I might as well go for it, take a guess, who knows'.

Yeah. Go for it, yeah.

Later, K10 clarified that his/her use of guesswork often depended on his/her mood:

I mean, are there any times where your guess has been successful? Do you remember, recollect?

Not... I don't really remember it, um, well, but I'm sure there has been a probability.

So, you think, so you're given the option of 'I don't know' and making a guess. Which one do you think is more attractive to click?

Um, it depends what, what sort of mood you're in.

At that time?

Um, it's probably quite your mood, it's probably quite a childish thing just to guess, but sometimes it's just a bit of a light-hearted thing, isn't it?

Ok. So you base it on that. If you're in a very positive mood...

Yeah.

... which one are you likely to go for?

Probably just guess.

6.6.4 GUESSWORK AND IMPLICIT LEARNING

Although guesswork is usually viewed as being counter-productive to learning, interviewee responses suggest that guesswork, in a limited context, may actually stimulate, instead of obstruct, learning. The conventional wisdom is that students should refrain from guessing if they do not know the answer to a question, and that students who adopt this approach would benefit more from the learning process. However, comments from students in Group 2 indicated that *not guessing* could be counter-productive to learning within the context of responding to EVS questions. Student comments implied that refraining from guessing was tantamount to *mentally disengaging* with a mathematical task. This mental engagement with a task, as described by Group 2 students who employed exploratory guesswork, which would otherwise not occur had the students refrained from guessing, has learning implications.

In a phenomenon known as implicit learning, a feeling of disorientation, which is what is produced when students are presented with a problem that causes them to resort to an exploratory guesswork strategy, 'may prime the brain to sense patterns it would otherwise miss – in mathematical equations, in language, in the world at large' (Carey, 2009). So when a student sees a question that s/he does not have an answer for at that moment; instead of 'shutting down' the thinking process by refraining from making a guess, s/he may instead try to make sense of the question by taking an inventory of his or her general knowledge or awareness about how to solve problems within that task domain. This conscious attempt at answering the question, based on a feeling of disorientation or what Proulx and Heine (2009) refer to as a 'meaning threat' is what seemingly produces an implicit learning outcome (see also Hirsh & Inzlicht, 2010). Implicit learning, within the EVS domain, is thus an offshoot of deliberate practice i.e. cognitive engagement, as students have to *think* about how to solve a problem, which might initially appear to be beyond their capacity.

The main difference between educated guesswork and exploratory guesswork is that students employing the former usually have some level of mathematical knowledge about how to solve a problem and may be vacillating between one or two options (e.g. in Q3, as illustrated in Figure 6.4, there are two possible groups of answers, depending on whether the final outcome is a vector or scalar quantity), or a need to avoid detailed work required to get to the answer (e.g. adopting an elimination approach to answering Q3). A typical characteristic of the educated guesswork approach is that the student usually starts with, or has a compelling rationale for the selections or choices made, or as K6 puts it, 'Um, as long as you have a basis to why you think it's that, then that

would be an educated guess.' In contrast, those employing the exploratory guesswork mode do not initially start with a compelling rationale. Rather, they work their way through the problem until they are able (though it could be expected that this goal may not always be accessible) to make a selection that they could provide a rationale for. But in the end, they also have a cognitive basis for their answer choices.

Implicit learning has also been alluded to in mathematics education literature. Polya (1966, 1954), described the use of careful guesswork, which he termed *plausible reasoning*, to facilitate the development of geometric intuition and mathematical thinking. Further, Burn (2002) explained how guesswork or conjecture', which is similar to the exploratory guesswork pathway through which some of the interviewees profiled in this study arrived at a formal product (the answer to the question), as a 'genetic process' - part of the process for the generation of mathematical thinking, and advocates a pedagogy that would utilise these mathematical building blocks:

The genesis of mathematics lies in experiment, trial, hunch, guesswork and intuition. In mathematical terms, the formulation of conjectures or hypotheses, making guesses and suppositions, play an important and necessary role in the development of research, even when further work clarifies the status of guesswork, and conjectures, either get no mention (when they are false) or are called theorems (if they can be justified) when the work is finally justified. For the research worker, the generation of conjectures is a necessary step in the growth of his or her knowledge. The ideas that students pick up may be false or may be open to refinement. Either way, they share some aspects of a conjecture. A pedagogy that deals regularly in conjectures and their refinement will be touching the genetic process more often than one that only provides systematic deduction. (p23)

One reason why guesswork is 'frowned upon' is because learners cannot often provide a 'systematic deduction' account of how they arrived at a solution. But this does not necessarily mean that there might have been no elements of deductive reasoning in their guesswork approach. For instance in the study earlier cited, Burns posited that 'pattern-spotting and pattern description are central processes in the genesis of mathematics' (Burn, 2002, p25). From an implicit learning perspective, the mechanism of 'pattern spotting' is how students arrive at a solution to a problem that might have initially left them feeling disoriented. To get the answer to a question, students employ guesswork as a means of deciphering the structure or 'pattern' to answering the question. It should be noted that although Burns (2002) described genetic processing mainly in terms of formal mathematics – 'concepts, axioms, definitions and sets' (p20), he alluded to the fact that the 'principles exposed are also relevant to applications of mathematics' (p21).

6.7 CONCLUSION

This chapter was designed to answer the research question, How has the use of EVS questions influenced (or otherwise) student approach to learning mathematics i.e. at the task level? To answer this question, I have presented documentary evidence and data from interviewee transcripts on how the course context and the use of specific EVS question types within the context of formative teaching have influenced student approach to solving mathematical tasks or problems. I have also shown how the use of calculators and guesswork within the EVS environment influence student learning approaches.

Under Course Context, I presented evidence on how the module specification for the mathematics module investigated induces a procedural deep approach to problem solving. I showed how the assessment (coursework) structure seems to encourage a procedural surface approach to learning, while the examination structure appears to elicit a procedural deep one. I presented evidence on how a quick lecture pace within the context of a heavy course load may encourage a surface approach to learning. I explained how the module structure seems to encourage a procedural deep learning approach, and the positive attitudes displayed by students towards mathematics help facilitate a more engaging approach to learning mathematics. Similarly, I presented evidence on how instructor enthusiasm and adoption of relevant pedagogical practices could help move students towards a more holistic and enthusiastic approach to learning mathematics.

As explained in the Formative Teaching section, specific EVS question types were used to facilitate learning. These question types in turn often influenced how students answered the respective questions. I presented evidence on how conceptual introducers and ConcepTests are often helpful in inducing a deep approach to learning. In contrast, I showed how direct introducers and revisions, especially when some of the distracters in the respective questions could be shown to be inaccurate via an elimination strategy, largely induce a procedural surface approach to problem solving. Meanwhile, applications largely induce a procedural approach while the approach elicited by repeaters depends on the type of the original question that is being repeated.

The evidence presented indicates that calculator use, within the EVS-enabled formative teaching paradigm, often induces a procedural surface approach to learning.

Further guesswork, which is often correlated with a surface approach to learning, was shown to be, within the context of exploratory guesswork usage, a facilitation or demonstration of the pursuit of a deeper approach to learning. This observation was explained as a possible instantiation of the phenomenon or learning process known as implicit learning.

In summary, the answer to the research question that guided this study is that EVS use has had a varied impact on student approach to problem solving. Although the course context appears to predilect the course of learning towards a procedural deep approach, some question types and calculator usage tilt the balance towards procedural surface. However, what is unequivocal is that the use of questions i.e. the EVS question types presented, and indeed the course context (largely) induce a *procedural* approach to learning. The type of procedural approach facilitated in each instance would depend on the task or question characteristics used in a particular instance.

The unique contributions of this study include the exposition of the impact of specific tasks and other factors embedded within the learning environment on the approach(es) that students adopt towards learning. This has been recognised in literature as important for the advancement of understanding on the influence that tasks within specific disciplines exert on student approaches to learning.

Second, I have conducted an exploration of the impact of calculator usage on student approach to problem solving. The significance of this is that a comprehensive, national (US) study on mathematics teaching and learning requested studies such as this to probe the effects on 'computation, problem solving and conceptual understanding' (NMAP, 2008, p24).

Third, I have presented an exposition of how guesswork, in some instances, may help facilitate, instead of negate, a meaningful approach to learning. This is in contrast to the conventional perception of guesswork as being generally detrimental to learning.

In the next chapter, I will present a review of the main findings of the studies presented in Chapters Two to Six. This will be followed by a synthesis of selected findings and the highlighting of areas of interest which future research on EVS use can address. I will also highlight the contributions of this research on EVS use to the literature on the role of educational technologies in mathematics teaching and learning, and then conclude the thesis by presenting concise answers to the research questions (see Chapter 1.4).

CHAPTER SEVEN

DISCUSSION AND CONCLUSION

7.1 INTRODUCTION

The focus of this thesis has been the evaluation of the impact of Electronic Voting Systems (EVS) on university mathematics teaching and learning. In **Chapter One**, I presented evidence that indicated that the proliferation in the use of (specific) educational technologies is often not linked to evidence of the beneficial impact or otherwise of such technologies. In that chapter, I also presented the literature review, synopsis of the studies that are not included in this thesis, and an overview of the contents of the chapters comprising the thesis. In the next section, I will present a brief review of the contents of Chapters Two, Three, Four, Five and Six, by focusing mainly on the findings. In subsequent sections, I will present a synthesis of the findings, a list of recommendations based on the findings, the research contributions of this study, potential topics of interest for future research, and a resolution of the research questions.

7.2 REVIEW OF FINDINGS

In **Chapter Two**, I presented the design, conduct, data analysis, reliability and validation procedures, and the findings of a cross-sectional survey study about the impact of EVS use on mathematics teaching, based on submissions by UK-based academic staff. The study was undertaken to provide insights on the research question, What are the views of academic staff using EVS on the impact of the technology on their teaching of university mathematics? I also explained how the conversational framework is useful in explaining the reported impact (in literature) of EVS use on student engagement and feedback.

The study findings indicated that 93.8% of the participating staff view EVS as a 'tool that can significantly enhance the teaching of university mathematics'. Feedback

was strongly identified as a major benefit of EVS use. Based on feedback from students, staff stated that they were able to identify common student errors or misconceptions, components of topics that students find difficult, student understanding of previous lessons, and the ease/difficulty levels of the EVS questions used. Similarly, staff stated that EVS use significantly facilitated feedback, through the provision to students, explanations of why student answers and other selected options are incorrect, step-by-step solutions of problems given in class, and discussion of the distribution or spread of students' correct and incorrect answer submissions.

Further, four pedagogical principles were identified as being the most compelling rationale that staff provided for the creation of EVS questions. These principles are: To receive feedback on student understanding, reinforce lecture material, enhance student engagement, and create good questions that would challenge students. Similarly, the EVS questions used by staff could be categorised into the four question types: Recall, application, conceptual understanding and ice breakers.

In **Chapter Three**, I presented the research methodology, including the analytical techniques and reliability/validity measures I adopted for the interview study, the results of which are presented in Chapters Four, Five and Six. Chapter Three thus included the presentation of the rationale for the adoption of qualitative research design, the semi-structured interview protocol, as well as sample recruitment and characteristics. I also explained in detail how interview data was transcribed and analysed via the thematic analytical approach. In addition, I specified the ethical regulations I observed in the conduct of the study. Further, I described how I established the internal validity (i.e. credibility), external validity (i.e. transferability), reliability (i.e. dependability) and objectivity (i.e. confirmability) of the study.

In **Chapter Four**, I presented evidence from the interview study on the kind of impact EVS use had had on students' emotional, behavioural and cognitive engagement. Under emotional engagement, I described how students viewed EVS as creating a favourable learning environment, and how the anonymity feature of EVS facilitated increased student participation by helping to mitigate student anxiety about being embarrassed in front of their peers. I also explained how the display of student answers often helped to reassure struggling students, and how getting a question right or wrong could produce mixed emotions in students. In addition, I stated how this self-reported impact of EVS use on emotional engagement could not be attributed to the novelty factor due to the two year exposure of the students sampled to EVS technology.

Under behavioural engagement, I explained how EVS use serves as a way of initiating, maintaining or re-focussing student attention in class. I also described how EVS facilitates increased student participation, while enhancing instructor-student, student-instructor, and student-student interactions. Further, I explained how the use of EVS questions in lectures facilitates deliberate practice, which in turn helps students to cognitively engage with learning material. I described how this practice helps students to not only identify areas where they might be struggling, but also to highlight strategies for overcoming observed difficulties. I also described how students often did not do any follow-up work to address gaps in their understanding, which were highlighted via deliberate practice.

Apart from highlighting disadvantages associated with EVS use such as the use of poorly designed questions, I described how the different engagement strands essentially overlap in the realities of the classroom environment. I explained how students often need to feel an emotional connection with mathematics or the learning environment, before they can involve themselves in learning activities and meaningfully engage with learning material. In addition, I presented evidence, which suggests that EVS use has not had a discernible impact on student academic performance, attendance or retention.

In **Chapter Five**, I employed a multi-theoretical framework comprising the approaches to learning (ALT) theoretical framework, goal theory and the strategic approach construct to characterise student learning approaches. Using this multi-theoretical framework, interviewed students were characterised as displaying procedural surface, procedural deep or conceptual deep approach to learning. Through the use of embodied symbolism for the secondary analysis of data, I was able to distinguish between levels of understanding displayed by students characterised by the adoption of conceptual deep approaches.

Further, I described how there seemed to be no association, based on primary data analysis, between the type of approach adopted and student academic performance. I also explained how an over-reliance on rehearsal strategies prioritises short term performance on assessments over long term acquisition of mathematical thinking skills. I described how students often need extended time to develop conceptual understanding, and how they might require external affordances and/or instructional measures that would give them the skills and confidence to reflect and monitor their own comprehension levels, so as to make the necessary metacognitive adjustments.

In **Chapter Six**, I presented documentary evidence and data from interviewee transcripts on how the course context and the use of specific EVS question types within the context of formative teaching have influenced the type of learning i.e. procedural surface, procedural deep and conceptual deep approaches that students adopt for solving mathematical problems.

I also presented evidence on how the course specification for the mathematics module investigated induces a procedural deep approach to problem solving. I showed how the coursework (assessment) structure seemed to encourage a procedural surface approach to learning, while the examination structure appeared to elicit a procedural deep one. I presented evidence on how a quick lecture pace within the context of a heavy course load may encourage a surface approach to learning. I explained how the module structure seemed to encourage a procedural deep learning approach. Further, I presented evidence on how instructor attributes such as enthusiasm and content knowledge were viewed positively by students.

Further, I explained how specific EVS question types were used to facilitate learning, and how these question types in turn often influenced the type of learning approaches students adopted towards solving the requisite questions. I presented evidence on how conceptual introducers and ConcepTests are often helpful in inducing a deep approach to learning. In contrast, I showed how direct introducers and revisions, especially in instances where it is possible for students to *eliminate* some of the distracters in the respective questions, largely induce a procedural surface approach to problem solving. I also described how applications' questions largely induce a procedural approach.

Moreover, I showed how the use of calculators and guesswork influence student learning approaches. I presented evidence on how calculator use, within the EVS-enabled formative teaching paradigm, often induces a procedural surface approach to learning. I also described how guesswork, which is often correlated with a surface approach to learning, is often a demonstration of the pursuit of a deeper approach to learning within the context of exploratory guesswork usage, and as explained through the process of implicit learning.

7.3 SYNTHESIS OF FINDINGS

In this section, I will present a synthesis of selected findings, which, I think, are germane to advancing knowledge on the role and impact of EVS use on mathematics teaching and learning. This synthesis will focus on EVS role as a catalyst for feedback, the association between EVS use and learning gains, a view on the interdependence of the procedural, and conceptual learning approaches. As a corollary to this synthesis, a reflection on the technologies that may replace EVS in future mathematics classrooms will also be presented.

7.3.1 FEEDBACK AS A FUNCTION OF DELIBERATE PRACTICE IN A FORMATIVE TEACHING ENVIRONMENT

From both the results of the survey and interview studies presented in this thesis, as well as evidence from literature, feedback appears to be the most important teaching and learning benefit attributable to EVS use. This feedback is a function of deliberate practice (Chapter 4.5), which itself is predicated upon the use of specific question types within a formative teaching/assessment paradigm, as described in Chapter 6.3. The authors of a comprehensive study on mathematics education (NMAP, 2008) stated that the 'use of formative assessments in mathematics can lead to increased precision in how instructional time is used in class and can assist teachers in identifying specific instructional needs' (p48).

In the EVS classroom, formative assessment is implemented through deliberate practice (DP). DP gives students not only the opportunity to work on a problem while the relevant subject is still fresh in their minds, but it also gives them a means for diagnosing their level of understanding of (how to solve) a problem. This is corroborated by the statement that 'there is a huge overlap between what is activated in a brain by thinking about an activity and what is activated when you actually perform that activity' (Heid, 2005, p358; as quoted in Olive et al., 2008, p154). This was attested to by one of the students I interviewed (K9), who stated that: 'Well, when you go through an example, or maybe C's teaching you something, I sometimes think 'oh, I get that', but it isn't until you do a question that you actually know if you can or not'.

While DP helps engage students with learning material and also serves a diagnostic function, EVS makes this engagement explicit by serving as a means for feedback provision. So student K9 quoted earlier can, for instance, determine whether

his/her initial assessment about his/her level of understanding was right or wrong. S/he could also see how s/he performed relative to the class. In addition, the spread of results indicates to the instructor whether to review or move on from a topic. In essence, EVS provides feedback to students on their levels of understanding, both in an absolute and relative sense i.e. relative to the class. Also, instructors receive feedback on areas where students are struggling, and may tailor instruction accordingly.

To represent the associations between formative assessment, deliberate practice and provision of feedback as a result of EVS use, it is constructive to review the conversational framework (Laurillard, 2002, 2008, see also King & Robinson, 2009a; and Cutts et al., 2004), introduced in Chapter 2.1.2 (see Figure 7.1 below). In the framework, the 'practice environment' is essentially analogous to the formative assessment paradigm described earlier, and which is facilitated by EVS technology. Similarly, 'learner's practice' is essentially deliberate practice i.e. students being given questions to answer in real time during lectures. The feedback loop is activated via the provision of feedback through the use of EVS displays. The feedback loops are three-pronged: the feedback that students get from being immersed in deliberate practice i.e. working on a problem, the feedback students get from instructors, and the feedback that students provide to the instructors.

In theory, these continuous interactions between formative assessment/teaching, deliberate practice, and feedback should lead to increase in learning gains. Why then was no association found between regular EVS usage and improved student academic performance, as reported in Chapter 4.8? Also, why have recent studies (e.g. Johnson & Robson, 2008; Bugeja, 2008; Socol, 2008) failed to find correlations between EVS usage and improved student performance? In the next section, I will present my postulations about the factors responsible for the observation that EVS use is not necessarily associated with learning gains.
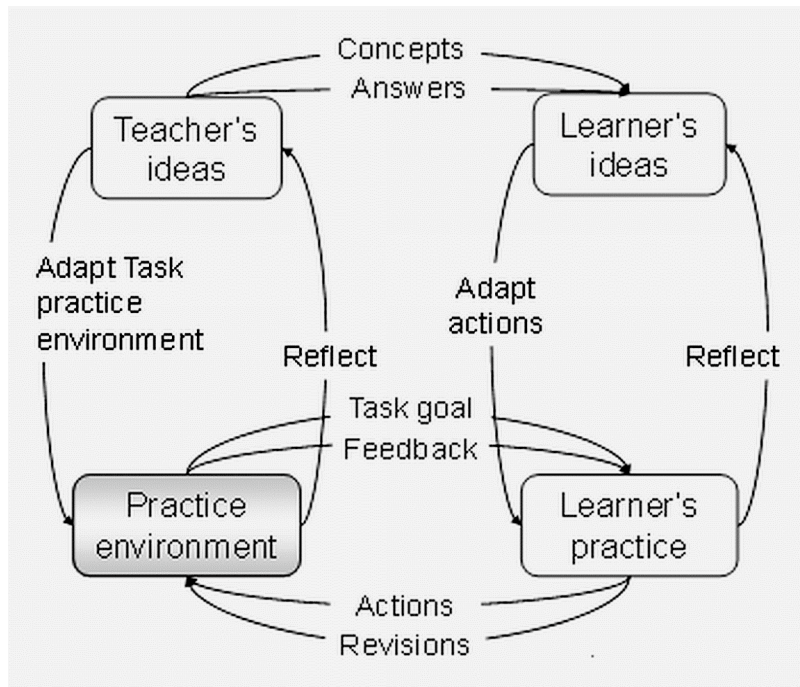
Figure 7.1 A modified version of Laurillard's conversational framework for evaluating educational technologies (Laurillard, 2008).

7.3.2 LEARNING GAINS AND EVS USE

As mentioned earlier, EVS use has not been shown to produce learning gains, defined here as increase in student academic performance, as measured by standardised assessment measures, in many studies. I would like to propose that this might be due to a number of factors. In this section, I will briefly present these factors.

Rationale for the Adoption of EVS

The first factor is that the rationale for using EVS could influence the associated learning gains or otherwise. From the studies reported (and excluded) in this thesis, classroom observations, study visits, and literature review, EVS-using instructors may be classified into three. The first group are those who adopted EVS, often in conjunction with other tools, as a way of radically changing pedagogical practices in order to address an identified learner need(s). For example, both Eric Mazur[29] and Jim Boyle[30] adopted EVS as one tool, in a suite of tools, to address student conceptual (understanding) deficiencies. Moreover, these EVS implementations were preceded by

---

[29] Harvard University

[30] Strathclyde University

303

a long period of reflection, fact-finding and significant re-design of curricular materials and classroom learning spaces. The early studies produced from these initiatives reported significant learning gains (e.g. Crouch & Mazur, 2001; Boyle et al, 2001). This first group of EVS users seems to be a minority.

The second group of EVS users are those who were introduced to EVS use through a relevant presentation or institutional initiative on EVS (see Chapter 2.6.2). My observation is that these users generally lack a singularly compelling rationale for the adoption of EVS. They have generally seen EVS as a way of enhancing their teaching and helping students learn better. In my view, most EVS users fall into this category, and I am not certain that the learning gains reported for this group of users will be the same as gains for the first group.

The third group of EVS users are those who are mandated or had to adopt EVS for their teaching because of a departmental/institutional policy or initiative. The practice of requiring instructors to use EVS is far more prevalent in the US, and has generated feelings of resentment in instructors forced to use EVS (see Bugeja, 2008, for instance). My view is that this group of users cannot be expected to have either the compelling rationale of the first group or the enhancement motive of the second. Extending that logic, it is not far-fetched to assume that the attendant learning gains might not be the same as those reported for the first and second groups. I should point out, however, that the third group of users do not always have conflicted views about EVS use.

In summary, the rationale for the adoption of EVS use could be expected to influence how instructors integrate EVS into their pedagogical practices (e.g. Lavicza, 2010; Laborde & Strasser, 2010). This could then impact the results obtained in the classroom. The importance of the rationale for using EVS leads me to the next factor, which is what instructors think about mathematics and technology.

Teacher's Ideas

The first two groups of users earlier described have a self-initiated, pedagogical rationale for using EVS. To achieve sustainable and valid learning outcomes, this pedagogical rationale must be integrated into the instructor's conceptions and beliefs about mathematics teaching and learning, and the role of technology in facilitating this (Laborde & Strasser, 2010; Lavicza, 2010) i.e. 'teacher's ideas' (see Figure 7.1). In the conversational framework (Figure 7.1), 'teacher's ideas', is presented as not a static, but a continuously reflected upon and regularly updated concept, in response to evolving

classroom and learner needs. This is corroborated by the statement: 'It is not a trivial matter to use technology effectively in classrooms. Teachers need to rethink maths and children's learning of maths as well as develop new and substantially different skills for teaching and assessment' (ICME10, p149, as quoted in Laborde & Strasser, 2010). So within the context of EVS usage, an instructor not only has to adapt teaching in response to feedback, but also the whole course content needs to be re-aligned in response to the continuous feedback received from students. One instructor has achieved this by presenting students with integrated question sets, which are aligned such that answers to the linked questions provide an indication of actual student understanding (Russell, 2008).

In addition, tasks that would help learners achieve the desired outcomes need to be designed and evaluated. Olive et al. (2008) recommended that instructors should be focusing on 'designing tasks that are transformed by the technology, leading to new mathematical practices…rather than tasks that could be just as easily completed without the technology' (p167). All these take time, a resource that instructors do not have, and effort. Moreover, instructors may not have the motivation to devote that much time to updating their ideas due to the perception that the additional time to develop teaching is not rewarded (Lavicza, 2010, p11).

In summary, if a teacher's ideas are not reviewed and updated as appropriate, the net effect of this lack of responsiveness to learner and classroom needs might be that EVS use has a negligible impact on learning outcomes. But the responsibility for the achievement of learning objectives rests not only with the instructors, but also with the learners themselves. In the next section, I will focus on the role of learners, as an important factor to consider.

Learners' Ideas

Just as 'teacher's ideas' need to be updated, so also do 'learner's ideas' (Figure 7.1). Learner's ideas **'**represent current student understanding and prior knowledge of a given subject' (King & Robinson, 2009a). For improvement in learning to occur, learners must regularly update their ideas and conceptions about a subject, in response to deliberate practice and feedback received from instructors. While feedback underpinned by deliberate practice helps learners to identify their gaps in their understanding (e.g. Nicol & Macfarlane-Dick, 2004; Black & William, 1998), it is often only by subsequent work or deliberate practise, especially outside the classroom, that these identified gaps may be closed. However, the evidence from the interview data (see

Chapter 4.5.4) and from talking informally with instructors and students, suggests that 'learner's ideas' are not being updated. In real learning terms, a student who knows where s/he is struggling, but has not taken the necessary steps to address the problem(s), cannot be expected to improve in a significant way.

Technology Window and Professional Development

Another factor to consider is what I refer to as the two-year technology window. Research evidence indicates that benefits from technological intervention in the classroom often start to appear from the second year of implementation (Somekh et al., 2007). Meanwhile, a significant number of studies evaluating the impact of technology on student performance are cross-sectional in design, often one academic semester long in duration. It would be more expedient, considering the two-year window, to conduct long term evaluations of technology impact. In addition, academic staff need to have targeted or discipline specific professional development training to fully utilise the potentials of technology in their teaching, and to help students learn better.

In summary, the factors that might be responsible for the seeming negligible impact of EVS use on student performance include the lack of a compelling pedagogical rationale for the adoption of EVS. The fact that instructors often do not review, reflect and update their ideas and conceptions about mathematics teaching and learning, and the role of technology in the mathematics classroom is another factor. Similarly, students often do not put in extra effort to address identified gaps in their own understanding, and so fall short of the desired learning outcomes. In addition, instructors need time to develop expertise and confidence with using technology. They also need targeted professional development opportunities.

In the next section, I will illustrate how 'teacher's ideas' and 'learner's ideas' (Figure 7.1) influence the adoption of a conceptual understanding approach to teaching and learning.

7.3.3 TEACHER'S/LEARNER'S IDEAS AND CONCEPTUAL UNDERSTANDING

The adoption of a conceptual understanding approach is often seen as the apex or preferred learning approach for students to adopt (e.g. see Haggis, 2003; Devlin, 2007, etc). While this is generally a good idea, I would like to highlight three issues that

would help put the advocacy for the adoption of a conceptual understanding (CU) approach in a more balanced perspective.

First, it could be argued that many instructors might be unprepared to teach in a way that fosters the adoption of a CU approach. This is because they themselves were taught mathematics in a procedural way i.e. they experienced procedural mathematics teaching and learning as a met-before. To teach in a way that fosters CU would require instructors to radically re-adapt their ideas about what it means to teach and learn mathematics. For example, the process that a teacher or learner undertakes in understanding a concept is often characterised by considerable 'struggle':

Mathematics is amazingly compressible: you may struggle a long time, step by step, to work through some process or idea from several approaches. But once you really understand it and have the mental perspective to see it as a whole, there is often a tremendous mental compression. You can file it away, recall it quickly and completely when you need it, and use it as just one step in some other mental process.   *(William Thurston, as quoted in Tall, in press, p4-2)*

Obtaining the 'mental perspective to see a process as a whole' takes considerable time and effort, and these would need to be taken into consideration in encouraging instructors to adopt more CU-focused approaches.

Similarly, many students have either significantly or only experienced procedural mathematics teaching, which has in turn influenced them to adopt procedural approaches. A shift to CU would also require considerable struggle and initial investment in time. From this perspective, a change in a student's approach from procedural to CU would require a change in teaching from an emphasis on procedural to CU-based instructional measures. This must also take into account the need that students might have for extended time to attain mastery of the relevant concepts. This leads me to the question of whether concurrent understanding (see Chapter 5.3.3) i.e. the intention to understand the relevant concept(s) of a body of learning material at the initial point of meeting is always a realistic or attainable goal.

Procedural vs. Conceptual Understanding

The impression that one gets from the debates surrounding the adoption of surface vs. deep, or procedural vs. CU by students is that deep or CU approaches are to be (always) preferred or promoted above surface or procedural approaches (e.g. Haggis, 2003; Case & Marshall, 2005; Devlin, 2007). I think these debates are misguided for a number of reasons. First, in the reality of the classroom and in many subjects, especially (engineering) mathematics, the attainment of CU is often preceded by the adoption of

procedural approaches. Devlin (2007) asserts, for example, that although Isaac Newton invented calculus (along with Leibniz), he 'did not have (conceptual) understanding of the concepts that underlay calculus as we do today - for the simple reason that those concepts were not fully worked out until late in the nineteenth century, two-hundred-and-fifty years later'. Likewise, it is possible for students to proceed, initially, with procedural knowledge, which may eventually culminate in conceptual understanding. We might be rendering students a disservice by discounting altogether procedural approaches to teaching and learning.
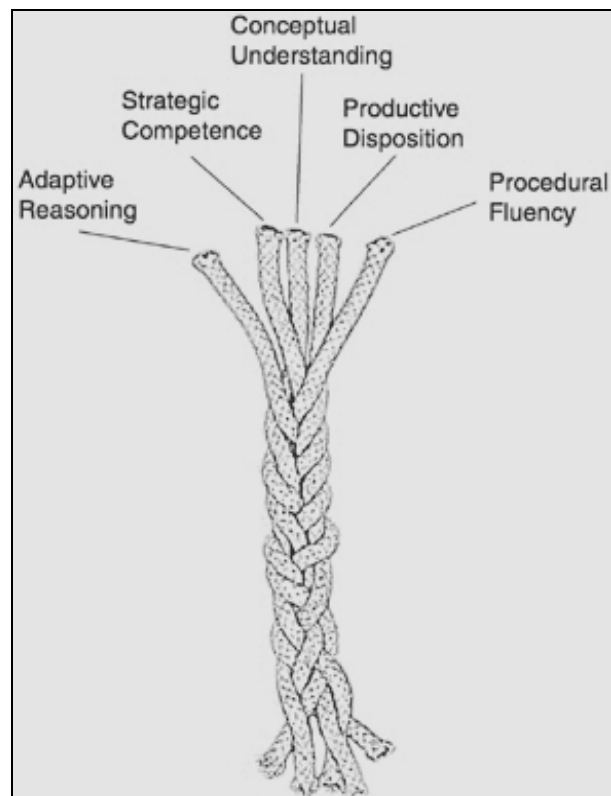
Figure 7.2 The five strands of mathematical proficiency. Source: NRC – National Research Council (2001).

So what could be the balance between the adoption and promotion of procedural and CU-based approaches? The approach advocated by the authors of the NRC (2001) report seems to be the most balanced. They presented procedural and CU-based approaches as representing two strands of the same interwoven and interdependent fibre of mathematical proficiency [In fact, the other three strands they presented, Strategic Competence, Adaptive Reasoning, and Productive Disposition, could possibly be rearranged under either procedural or conceptual understanding]. Similarly, the authors

of the comprehensive NMAP (2008) study reiterated the 'mutually reinforcing benefits of conceptual understanding, procedural fluency, and automatic (i.e. quick and effortless) recall of facts' (pxiv).

In summary, a balanced approach would be to emphasise both procedural and CU approaches, with the proviso that even when a procedural approach is emphasised or adopted, the long term goal would be CU. In the next section, I will describe how the practice environment (Figure 7.2) within the conversational framework, which is currently epitomised by EVS use, might change in the future to accommodate new or alternative technologies.

7.4 ALTERNATIVE TECHNOLOGIES

The practice environment within the conversational framework is currently enabled by EVS technology. However, there are alternative technologies, which are either being used or have the potential to replace EVS (e.g. Cheung, 2008; Esponda, 2008). These technologies include the use of free or proprietary polling systems such as SMSPoll[31] and PollEverywhere[32], and the use of Twitter e.g. TwEVS[33]. A common feature of these applications is that they are dependent on the mobile phone, the ubiquitous tool that has the potential to provide both students and academic staff with anytime, anywhere access to learning and teaching resources (e.g. Jones et al., 2006; King, 2007).

Other alternative technologies which have been or could be used to provide the same benefits that may be derived from EVS use include networked tablet PCs (e.g. Hamilton & Hurford, 2007; King et al., 2008), and TI Nspire Navigator (e.g. Clark-Wilson, 2008; Dougherty, 2005). Further, I would like to propose that the factors that would determine the rate of uptake and sustainability of use of these potential EVS replacement technologies would include the following:

- The cost of using the systems. Systems that are free or inexpensive to purchase and maintain are likely to gain ascendancy;
- The ease and simplicity of using the systems;

---

[31] http://www.smspoll.net/.

[32] http://www.polleverywhere.com/sms-classroom-response-system.

[33] http://www.rsc-ne-scotland.org.uk/mashe/category/assessment/twevs/.

- The adaptability of the systems e.g. would they be as expedient to use in a conventional classroom as they would be in a studio or laboratory environment? Are they wireless or do they require cables?
- Can they be used for not only problems requiring short answers or responses, but also longer, essay--type problems requiring more detailed work or explanation?

In summary, mobile phone-based applications and other technologies have the potential to replace EVS in the classroom, but further research (e.g. pilot studies) is required to investigate how the use of these technologies would impact the university mathematics classroom. In the next section, I will present concise answers to the research questions upon which this thesis is predicated.

7.5 CONCISE ANSWERS TO THE RESEARCH QUESTIONS

What are the views of academic staff using EVS on the impact of the technology on their teaching of university mathematics (the focus of Chapter Two in this thesis)?

EVS use has influenced the teaching of university mathematics by changing the way students gauge understanding of learning material, and how instructors assess student understanding of learning material. The provision of feedback, via EVS use, means instructors are able to identify common student errors, topics that students find difficult, student understanding of previous lessons, and the ease/difficulty levels of the EVS questions used. Similarly, they can also provide, to students, explanations of why erroneous student answers are incorrect, and step-by-step solutions of problems given in class.

How has the use of EVS impacted (or otherwise) student engagement with respect to the learning of mathematics at university (Chapter Four)?

EVS has positively impacted how students feel (emotional engagement), behave (behavioural engagement) and think (cognitive engagement) in class. The anonymity feature helps students to overcome the fear of looking stupid, while students also view EVS use as being responsible for the creation of a favourable learning environment. Further, EVS use helps focus student attention, increases participation and enhances interactivity. Moreover, deliberate practice helps students to cognitively engage with learning material.

What is the student's approach to learning mathematics (Chapter Five);

The 10 students interviewed displayed procedural surface, procedural deep and conceptual deep learning approaches with respect to the integrated approaches to learning (ALT) framework. The employment of the embodied-symbolism construct also helped reveal qualitative differences in the levels of understanding of the four students characterised as displaying conceptual deep approaches.

How has the use of EVS questions influenced (or otherwise) student approach to learning mathematics (Chapter Six)?

The use of specific EVS question types tends to induce specific learning approaches in students. The EVS question types, conceptual introducers and concept tests, tend to induce procedural deep or conceptual deep approaches in students. Direct introducers and revisions largely induce a procedural surface approach, while applications tend to induce procedural surface or deep approaches.

7.6 STUDY CONTRIBUTIONS

In this section I will describe, on a chapter by chapter basis, the unique and general contributions that the research presented in this thesis has made to the body of knowledge on mathematics education and educational technologies. The description will be in two modes: Those that are specific to mathematics, and those that are not specific to mathematics.

Contributions specific to mathematics

The unique contribution of the study reported in Chapter Five is the novel, application of an integrated multi-theoretical framework to the analysis and characterisation of student approaches to learning mathematics. In addition, the criteria presented in Table 5.5 provide a coherent, qualitative framework that may be used to reliably characterise student approaches to learning mathematics. Second, the application of secondary analysis of data through the use of the embodied-symbolism construct provides a qualitative means for making explicit the (differing) levels of understanding present in the same ALT learning approach category.

The contributions of the study reported in Chapter Six include the exposition of the impact of specific mathematics question types or tasks, and other factors embedded within the learning environment, on the approaches that students adopt towards learning. Second, the study included an exploration of the impact of calculator usage on student approach to problem solving. The significance of this is that a comprehensive, national study on mathematics teaching and learning requested studies such as this to probe the effects on 'computation, problem solving and conceptual understanding' (NMAP, 2008, p24). Third, the study offers an exposition of how guesswork, in some instances, may help facilitate, instead of negate, a meaningful approach to learning mathematics. This is in contrast to the conventional perception of guesswork as being generally detrimental to mathematics learning.

In Chapter Four, the elucidation of the concept of deliberate practice helps explain how the use of EVS questions in lectures helps students to cognitively engage with learning material. This is particularly so due to the peculiar nature of mathematics, as students have to solve problems, as opposed to merely reading a text, to develop or advance their mathematical thinking skills or understanding. The concept of deliberate practice helps explain EVS utility in helping students identify areas where they might be struggling, and to explain why the absence of follow-up deliberate practice outside the classroom is often one of the factors responsible for the retention of gaps in student understanding, especially the gaps which had earlier been highlighted through deliberate practice in real time in the classroom.

The unique contribution of the study reported in Chapter Two is that it was a *novel* study, which focused on the presentation and description of the views and observations of academic staff, from various institutions, on the impact of EVS as a tool for university mathematics teaching. Research studies on EVS, apart from the invited contributions to books, have largely consisted of descriptions of research on EVS within specific institutional contexts. In contrast, I presented evidence of EVS effectiveness for *mathematics teaching* from staff working in 14 different institutional contexts and requirements in that study. These types of studies are required in order to adequately assess the evidence on EVS (and educational technologies in general) usefulness for mathematics teaching and learning (Sloane, 2008).

Last, my focus on EVS use at university level is a contribution to the research evidence on the use of technologies in mathematics teaching and learning at tertiary

level, given the paucity of research on the use of educational technologies in universities (e.g. Lavicza, 2010).

Contributions that are not specific to mathematics

The unique contribution of the study reported in Chapter Four is the detailed description of the impact of a specific educational intervention, EVS use, on students' emotional, behavioural and cognitive engagement with learning mathematics. The study included a novel presentation on the role EVS plays in stimulating, maintaining and directing student attention. The study is thus a contribution to meeting the need for studies of interventions to help illuminate how specific instructional measures influence (the different aspects of) student engagement (Fredricks et al., 2004).

Further, the evidence presented was based on qualitative research methodology i.e. semi-structured interviews, whereas studies on engagement are typically based on data from quantitative instruments. This qualitative approach helped provide thick descriptions of classroom contexts, which are often difficult to capture in inventory or survey-based studies (Fredricks et al., 2004). Included in the study was also evidence on the association or correlation of enhanced student engagement with increase or otherwise in student achievement. This explicit inquiry on associations between student engagement and achievement is often absent in research on student engagement.

Similarly, the study in Chapter Five, which was based on a qualitative interview approach to analysing/characterising student approaches to learning, provides an alternative view of investigating student learning in a field where the predominant means of inquiry is the use of inventories (see Chapter 5.1.1).

Last, the focus of this thesis on the evaluation of the impact of EVS on mathematics teaching and learning is generally a contribution to the literature on the impact of educational technologies on learning and teaching. In addition, I have provided detailed accounts of the methodological, analytical and reliability/validity procedures that I employed for both the survey and interview studies. This was done to ensure, among other issues, the replicability of the studies presented in this thesis.

7.7 RECOMMENDATIONS

First, instructors could present, where and when possible, learning material that challenges students to approach problems from a CU perspective. It was highlighted in

this study how conceptual introducers and concepts (Chapter 6.4) could be used to challenge students to think more holistically about a problem. Another example is the 'concepts-and-applications-before-skills approach to algebra and calculus' (Heid, 2003, p3). This approach is particularly suitable for a CAS environment where the software can perform the procedures so that students can focus on understanding the underlying concepts.

Second, to encourage students to adopt more balanced approaches i.e. ones that are not necessarily lopsided to either procedural or CU, the assessment structure would have to be correspondingly aligned to reflect this goal (e.g. Biggs, 1999). The University of Gloucestershire recognised the importance of this instruction-learning-assessment alignment, which is why in 2008, the University radically restructured its assessment regime to bring it in alignment with the institution's goal of promoting deep learning and providing better feedback. This restructuring was based on the rationale that:

"It is assessment that exercises the most profound influence on students' approach to their work. At Gloucestershire, the pursuit of assessment procedures that empower students, that match desired learning outcomes and that encourage deep learning, is an integral part of our educational philosophy". *(Patricia Broadfoot[34], as quoted in Atwood, 2007)*

Third, instructors could also, where and when feasible, convene a lecture session, such that only issues or problems that are important to students would be addressed during the session. The problems could be identified by having the students vote, via EVS, on a number of topics or issues at the beginning of the session. The session would then proceed based on student response. One way to facilitate this EVS-based, contingent teaching session is by implementing it for examination revisions. Currently, examination revision sessions are often structured such that the instructor goes through a predetermined schedule of revising topics covered in the relevant module.

Fourth, it would be a worthwhile effort for academic staff using EVS to teach mathematics to form a community for professional development purposes. This group could share expertise on effective question design and creation, time management, technical issues, etc. An example of a similar group but with broader goals is the Engaging Students Through In-class Technology Group (ESTICT[35]), but a more

---

[34] Prof. Patricia Broadfoot was at the time the vice-chancellor of the University of Gloucestershire.

[35] ESTICT: http://estict.ning.com/

focused and discipline-specific group or support forum is required to handle the peculiar challenges of mathematics teaching and learning.

Fifth, it is important for instructors to use well-designed questions. Students, as was shown in Chapter Five, can often discern when a question is either unsuitable, or has been used simply because the instructor wanted to present 'something' with the EVS system. Bruff (2009) recommends that instructors use the following questions as guide in drafting EVS questions: (1) What student learning goals do I have for the question; (2) What do I hope to learn about my students by asking this question; (3) What distribution of responses do I expect to see and what might I do if the actual distribution turns out very differently (p205)?

Sixth, it is also imperative to remind students, periodically, about the formative assessment purposes of using EVS. Otherwise, student interest and responsiveness might wane during the course of regular EVS use. Boyle (2006) emphasised the value of reminding students about the value of using EVS when he stated: 'We have found it important to explain why we teach in this way, and show evidence that it is worthwhile for the students to put thought, preparation, and effort into what happens in class' (p294). Perhaps this action may help students to re-align their mathematical ideas in response to the EVS feedback received.

Last, I think that it might be worthwhile to review the Loughborough University principle that marks obtained in the first year do not contribute to the final degree classification, as all that is required is a pass. As I showed with interviewees, K4 and K9, this principle has sometimes led some students to hold the notion that they do not have to apply themselves in their first year, as they could always 'accelerate' in the second year. The problem with this attitude is that the second-year modules in disciplines like engineering and mathematics are often predicated upon the learning material introduced in the first year. A student who did not take the first-year modules seriously could thus be expected to have serious difficulties in the second year. Perhaps a survey on how not taking the first year seriously impacts the performance of second-year students in numerate disciplines would be in order (As an alternative, a degree at the University of Warwick[36], which I have no affiliation with, used to be weighted thus: Year 1:10%; Year 2: 30%, Year 3: 60%).

---

[36] Prof. (Emeritus) David Tall provided me with this information.

7.8 FUTURE RESEARCH

The research presented in this thesis has addressed many issues, some of which could be extended by further studies. Some of the studies that would be particularly constructive to conduct in the future include:

- Longitudinal evaluation of the impact of EVS use on student engagement;
- Research to measure the impact of EVS use on student academic performance, under experimental or quasi-experimental conditions, i.e. with control and treatment groups, where possible;
- Research to address the potential benefits and pitfalls that may be associated with the adaptation of Twitter, live polling systems and other EVS replacement technologies for mathematics instruction;
  Research into how instruction and the learning environment may be (re)designed or adapted to help students develop metacognitive e.g. comprehension monitoring skills, so as to facilitate the adoption of approaches that focus on understanding learning material;
- Research on how, when and where it would be appropriate for mathematics instructors to deploy EVS in contingent teaching mode, especially to identify student misconceptions and/or areas of difficulty so that mathematical instruction could be corresponding adapted to address relevant issues;
- Research on whether aligning assessment mode with the predominant EVS usage mode produces any change(s) or otherwise in student academic performance;
- Research on how instructor's beliefs and conceptions of mathematics shape their use of technology (Bransford et al., 2000, p164; Lavicza 2010)
- Further research on how calculator usage might influence the approach that students adopt towards solving mathematics problems;
- Further research on the role and influence of guesswork in EVS-incorporating mathematics classrooms.

7.9 CONCLUSION

Research on instructional software has generally shown positive effects on students' achievement in mathematics as compared with instruction that does not incorporate such technologies. These studies show that technology-based drill and practice and tutorials can improve student performance in specific areas of mathematics. *(NMAP, 2008, pxxiii)*

The evidence presented in this thesis suggests that EVS is 'a tool that can significantly enhance the teaching of university mathematics', a statement that 93.8% of the academic staff polled in the survey described in Chapter Two agree with. Boyle (2006) further buttressed this when he stated that (the use of) 'audience responses systems have changed the classroom. Those of us who use them could not return to the conventional lecture – you get "hooked" on interpreting the feedback and finding out what is going on in students' minds – and it is different every year' (p302).

But it is imperative to note that EVS is only a *tool*, which if used well, could positively impact mathematics teaching and learning. This view of EVS as a tool is succinctly encapsulated by the statement that EVS systems or clickers 'don't "cause" the learning, any more than the paper in a physics textbook or the blackboard behind the faculty member "cause" learning. But like them, clickers are a powerful tool in the proper circumstances and in the right hands' (Steve Ehrmann[37], as quoted in Hake, 2008). In conclusion, EVS can be viewed as a tool which, when underpinned by a compelling pedagogical rationale, and a corresponding re-alignment in teachers' and learners' ideas about *the* mathematics which the EVS tool is used to be for, can enhance the quality of teaching and learning occurring in university mathematics classrooms.

---

[37] http://www.wcer.wisc.edu/archive/cl1/cl1/people/ehrmanns.htm

BIBLIOGRAPHY

Abrahamson, L. A. (2006). A brief history of networked classrooms: Effects, cases, pedagogy, and implications. In Banks, D.A. (Ed.), *Audience Response Systems in Higher Education: Applications and Cases (pp. 1-25)*. Hershey, PA: Idea Group Inc.

Ainley, J., & Luntley, M. (2007). The role of attention in expert classroom practice. *Journal of Mathematics Teacher Education,* 10(1)**,** 3-22.

Ames, C., & Archer, J. (1988). Achievement goals in the classroom: Students' learning strategies and motivational processes. *Journal of Educational Psychology, 80,* 260–267.

Anderson, L.W., & Krathwohl, D.R. (2001). *A taxonomy of learning, teaching and assessing: A revision of Bloom's taxonomy of educational objectives.* New York: Longman.

Angelo, T. A., & Cross, K. P. (1993). *Classroom assessment techniques: A handbook for college teachers* (2nd ed., pp. 148-153). San Francisco: Jossey-Bass.

Angelo, T.A., & Cross, P. (1990). *Classroom Assessment Techniques*. New York: Jossey-Bass.

Antonini, S. (2006). Graduate students' processes in generating examples of mathematical objects. In Novotná, J., Moraová, H., Krátká, M., & Stehlíková, N. (Eds.), *Proc. 30th Conf. of the Int. Group for the Psychology of Mathematics Education*, 2, 57-64. Prague, Czech Republic: PME.

Arcavi, A., & Hadas, N. (2000). Computer mediated learning: An example of an approach. *International Journal of Computers for Mathematical Learning*, 5(1), 25-45.

Asiala, M., Brown, A., DeVries, D., Dubinsky, E., Mathews, D., & Thomas, K. (1996). A framework for research and curriculum development in undergraduate mathematics education. *Research in Collegiate Mathematics Education II*, CBMS Issues in Mathematics Education, 6, 1-32.

Atwood, R. (2008). *Exams cut by 20 per cent in bid to improve assessment*. Available online (Retrieved May 10th, 2010): http://www.timeshighereducation.co.uk/story.asp?storycode=403656.

Baird, J. R. (1986). Improving learning through enhanced metacognition: A classroom study. *European Journal of Science Education*, 8, 263-282.

Banks, D. A. (Ed.). (2006). *Audience response systems in higher education: Applications and cases*. Hershey, PA: Idea Group Inc.

Barnett, R. (1990). *The idea of higher education*. Buckingham: Open University Press.

BBC (2010). *Students only have 10-minute attention span*. Available online (Retrieved February 10th, 2010): http://news.bbc.co.uk/1/hi/education/8449307.stm.

Beatty, I. D., Leonard, W. J., Gerace, W. J., & Dufresne, R. J. (2006). Question driven instruction: Teaching science (Well) with an Audience Response System. In Banks, D.A. (Ed.), *Audience Response Systems in Higher Education: Applications and Cases* (pp. 96-115). Hershey, PA: Idea Group Inc.

Becta (2009). *Evidence of the impact of technology on learning and educational outcomes*. Coventry: Becta. Available online (Retrieved November 7th, 2009): http://research.becta.org.uk/index.php?section=rh&catcode=_re_rp_02&rid=16813.

Becta (2003). *What the research says about using ICT in maths*. Coventry: Becta. Available online (Retrieved November 8th, 2009): http://research.becta.org.uk/upload-dir/downloads/page_documents/research/wtrs_maths.pdf.

Bell, J. (2005). *Doing your research project*: *A guide for first-time researchers in education, health and social science* (4th ed.). Maidenhead, UK: Open University Press.

Besa (2006). *Information and communication technology in UK state schools*. London: Besa.

Biggs, J. (2001). The reflective institution: assuring and enhancing the quality of teaching and learning. *Higher Education*, 41, 221–238.

Biggs, J. (1999). *Teaching for quality learning at university*. Buckingham: Open University Press.

Biggs, J. (1993). What do inventories of students' learning processes really measure? A theoretical review and clarification. *British Journal of Educational Psychology*, 63, 3–19.

Biggs, J. (1978). Individual and group differences in study processes. *British Journal of Educational Psychology*, 48, 266–279.

Black, P. & Wiliam, D. (1998). Assessment and classroom learning. *Assessment in Education,* 5 (1), 7-74.

Blodgett, D.L. (2006). *The effects of implementing an interactive student response system in a college algebra classroom*. Master of Science in Teaching Thesis, University of Maine.

Bloom B. S. (1956). *Taxonomy of Educational Objectives, Handbook I: The Cognitive Domain.* New York: David McKay Co Inc.

Blumenfeld, P. C., & Meece, J. L. (1988). Task factors, teacher behavior, and students' involvement and use of learning strategies in science. *Elementary School Journal, 88,* 235–250.

Bode, M., Drane, D., Kolikant, Y. B., & Schuller, M. (2009). A clicker approach to teaching calculus. *Notices of the American Mathematical Society*, 56(2), 253-256.

Booth, S. (1992). *Learning to program: a phenomenographic perspective.* Gothenburg: Acta Universitatis Gothoburgensis.

Boyce, C., & Neale, P. (2006). *Conducting in-depth interview: a guide for designing and conducting in-depth interviews for evaluation input.* Pathfinder International Tool Series. Available Online (Retrieved December 5th, 2009):
http://www.pathfind.org/site/DocServer/m_e_tool_series_indepth_interviews.pdf?docID=6301.

Boyle, J. (2006). Eight years of asking questions. In Banks, D.A. (Ed.), *Audience Response Systems in Higher Education: Applications and Cases* (pp. 289-304). Hershey, PA: Idea Group Inc.

Boyle, J., & Nicol, D. (2003). Using classroom communication systems to support interaction and discussion in large class settings. *Association of Learning Technology Journal*, 11(1), 43-57.

Boyle, J., Nicol, D., Hamilton, B., & Dempster, B. (2001). The use of classroom feedback systems to enable active learning in large engineering mechanics classes. *The International Conference on Engineering Education,* Oslo, Norway.

Bransford, J. D., Brown, A., & Cocking, R. (2000). *How people learn: Mind, brain, experience and school* (Expanded Edition). Washington, DC: National Academy Press.

Breidenbach, D., Dubinsky, E., Hawks, J., & Nichols, D. (1992). Development of the process conception of function. *Educational Studies in Mathematics*, 23, 247-285.

Bruff, D. (2009). *Teaching with classroom response systems: Creating active learning environments*. San Francisco: Jossey-Bass.

Bryman, A. (2008). *Social Research Methods* (3rd Ed.). Oxford: Oxford University Press.

Bugeja, M. (2008). Classroom clickers and the cost of technology. *Chronicle of Higher Education,* 55(15).

Burn, R. (2002). The genesis of mathematics structures. In Khan, P. & Kyle, J. (Eds.), *Effective Learning and Teaching in Mathematics and its applications* (pp. 20-33). London: Kogan Page.

Burton, L., & Jaworski, B. (1995). *Technology in mathematics teaching* (Eds). Chartwell-Bratt: Bromley.

Burton, L. (2002). Methodology and methods in mathematics education research: Where is the why? In Goodchild and English (Eds.), *Researching Mathematics Classrooms* (pp. 1-10). Westport, CT: Praeger.

Butler, M. (2005). What I learned from using a personal response system. *Mathematical Association of America FOCUS*, 25(3), 15.

Caldwell, J.E. (2007). Clickers in the large classroom: Current research and best-practice tips. *Life Sciences Education*, 6, 9-20.

Carey, B. (2009). *How nonsense sharpens the intellect*. Available online (Retrieved November 10th, 2009):
http://www.nytimes.com/2009/10/06/health/06mind.html?_r=2&em.

Carneson, J., Delpierre, G., & Masters, K. (1996). *Designing and managing multiple choice questions*. Available online (Retrieved May 10th, 2010):
http://web.uct.ac.za/projects/cbe/mcqman/mcqcont.html.

Case, J. M., & Marshall, D. (2004). Between deep and surface: Procedural approaches to learning in engineering contexts. *Studies in Higher Education*, 29 (5), 605-615.

Case, J. M. & Gunstone, R. F. (2003). Going deeper than deep and surface approaches: a study of students' perceptions of time. *Teaching in Higher Education*, 8, 55–69.

Case, J. M., & Gunstone, R. F. (2002). Metacognitive development as a shift in approach to learning: an in-depth study. *Studies in Higher Education*, 27, 459-470.

Case, J. M. (2000). *Students' perceptions of context, approaches to learning and metacognitive development in a second year chemical engineering course*. Ph.D. thesis, Monash University, Melbourne.

Cheung, S. L. (2008). Using mobile phone messaging as a response medium in classroom experiments. *Journal of Economics Education*, 39(1), 51-67.

Clark-Wilson, Alison (2008). *Evaluating TI-NspireTM in secondary mathematics classroom*. Research Report, University of Chichester.

Cline, K., Zullo, H., & Parker, M. (2007). Teaching with classroom voting. *Mathematical Association of America FOCUS*, 27(5), 22-23.

Coffey, A., Holbrook, B. & Atkinson, P. (1994). Qualitative data analysis: Technologies and representations. Sociological Research Online, 2.

Cohen, L., Manion, L., & Morrison, K. (2007). Research methods in education (6th ed.). London: RoutledgeFalmer.

Connell, J. P., Halpern-Felsher, B. L., Clifford, E., Crichlow, W., & Usinger, P. (1995). Hanging in there: Behavioral, psychological, and contextual factors affecting whether African American adolescents stay in school. *Journal of Adolescent Research, 10,* 41–63.

Crawford, K., Gordon, S., Nicholas, J., & Prosser, M. (1998). University mathematics students' conceptions of mathematics. *Studies in Higher Education*, 23(1), 87-94.

Crawford, K., Gordon, S., Nicholas, J., & Prosser, M. (1994). Conceptions of mathematics and how it is learned: The perspectives of students entering university. *Learning and Instruction*, 4, 331-345.

Croft, A.C. (2002). Mathematics - the teaching, learning and support of non-specialists. In Khan, P., & Kyle, J. (Eds.) *Effective Learning and Teaching in Mathematics and its applications* (pp. 144-157). London: Kogan Page.

Croft, A.C., & Ward, J.P. (2001). A Modern and Interactive Approach to Learning Engineering Mathematics. *British Journal of Educational Technology*, 32(2), 195-208.

Croft, A.C., Hibberd, S., Lawson, D.A., Mustoe, L.R., & Shaw, C.T. (2000). Engineering Mathematics in the UK: SARTOR - a Timely Opportunity for Reform. *Engineering Science and Education Journal*, 9(2), 77-87.

Crotty, M. (1998). *The foundations of social research: Meaning and perspective in the research process*. Sydney, Australia: Allen & Unwin.

Crouch, C. H., & Mazur, E. (2001). Peer instruction: Ten years of experience and results. *American Journal of Physics*, 69(9), 970-977.

Cutts, Q., Kennedy, G., Mitchell, C., & Draper, S. (2004). Maximising dialogue in lectures using group response systems. In *7th IASTED International Conference on Computers and Advanced Technology in Education,* Hawaii, USA.

Dahlberg, R. P., & Housman, D. L. (1997). Facilitating learning events through example generation. *Educational Studies in Mathematics*, *33*, 283–299.

Deemer, S., & Hanich, L. B. (2005). Using achievement goal theory to Translate Evidence-Based Principles into Practice in Educational Psychology. *Clearing House: A Journal of Educational Strategies, Issues and Ideas*. *78*(5), 197-198. Available online: http://www.redorbit.com/news/education/229666/using_achievement_goal_theory_to_translate_evidencebased_principles_into_practice/index.html#.

Devlin, K. (2007). *What is conceptual understanding?* Mathematical Association of America. Available online (Retrieved December 10th, 2009): http://www.maa.org/devlin/devlin_09_07.html.

Dougherty, B. (2005). *TI-Navigator™ Technology and Algebra I.* Curriculum Research and Development Group, University of Hawaii.

Draper, S.W. (2010). Catalytic assessment: understating how MCQ and EVS can foster deep learning. *British Journal of Educational Technology, 40* (2), 285-293.

Draper, S.W., & Brown, M.I. (2004). *Increasing interactivity in lectures using an electronic voting system. Journal of Computer Assisted Learning*, 20(2), 81-94.

Drew, S. (2001). Student perceptions of what helps them learn and develop in higher education. *Teaching in Higher Education*, 6, 309–331.

Drew, L., Bailey, S., & Shreeve, A. (2002). Fashion variations: student approaches to learning in fashion design. In Davies, A (Ed.), *Enhancing curricula: exploring effective curriculum practices in art, design and communication in higher education*. London: Centre for Learning and Teaching in Art and Design.

Duncan, D. (2005). *Clickers in the classroom: How to enhance science teaching using classroom response systems*. San Francisco: Pearson Education.

Dweck, C. S. (2000). *Self-theories: Their role in motivation, personality, and development*. Philadelphia, PA: Taylor and Francis.

Dynarski, M., Agodini, R., Heaviside, S., Novak, T., Carey, N., Campuzano, L., Means, B., Murphy, R., Penuel, W., Havitz, H., Emery, D., & Sussex, W. (2007). *Effectiveness of reading and mathematics software products: Findings from the first student cohort* Washington, DC: US Department of Education, Institute of Education, Institute of Education Sciences. Available Online (Retrieved May 14th, 2010): http://ies.ed.gov/ncee/pdf/20074005.pdf.

Entwistle, N. J. (1997). Reconstituting approaches to learning: a response to Webb. *Higher Education*, 33, 213-218.

Entwistle, N. J., & Ramsden, P. (1983). *Understanding student learning*. London: Croom Helm.

Esponda, M. (2008). *Electronic voting on-the-fly with mobile devices*. The 13th Conference on Innovation and Technology in Computer Science Education, Madrid, Spain.

Felder, R. M. (1996). Matters of style, *ASEE Prism*, 6, 18–23.

Fies, C., & Marshall, J. (2006). Classroom response systems: A review of the literature. *Journal of Science Education and Technology*, 15(1), 101-109.

Fischbein, E. (1993). The interaction between the formal and the algorithmic and the intuitive components in a mathematical activity. In Biehler, R., Scholz R.W., Straser, R., & Winkelmann, B. (Eds.), *Didactics of mathematics as a scientific discipline* (pp. 231–345). Dordrecht, Netherlands: Kluwer.

Fischbein, E. (1987). *Intuition in science and mathematics: An educational approach*. Dordrecht, The Netherlands: Reidel.

Flavell, J. H. (1979). Metacognition and cognitive monitoring: A new area of cognitive-developmental inquiry. *American Psychologist, 34,* 906-911.

Flavell, J. H. (1976). Metacognitive aspects of problem solving. In Resnick, L.B. (Ed.) *The nature of intelligence*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Frase, L. T., Patrick, E., & Schumer, H. (1970). Effect of question position and frequency upon learning from text under different levels of incentive. *Journal of Educational Psychology*, 61, 52-56.

Fredricks, J. A., Blumenfeld, P. C., & Paris, A. H. (2004). School engagement: Potential of the concept, state of evidence. *Review of Educational Research, 74, 1*, 59-109.

Geertz, C. (1973). Thick description: Toward an interpretive theory of culture. In Geertz, C. (Ed.), *The interpretation of cultures*. New York: Basic Books.

Goldenberg, E. P. (1995). Ruminations about dynamic imagery (and a strong plea for research). In Sutherland, R., & Mason, J. (Eds.), *Exploiting Mental Imagery with Computers in Mathematics Education*, 202-224. Berlin: Springer.

Gray, E., & Tall, D. O. (1994). Duality, ambiguity and flexibility: A proceptual view of simple arithmetic. *Journal for Research in Mathematics Education, 26*(2), 115–141.

Greene, J.C., & Caracelli, V.J. (1997). *Advances in mixed-method evaluation: The challenges and benefits of integrating diverse paradigms* (Eds.). New Directions for Program Evaluation (No. 74). San Francisco: Jossey-Bass.

Groveman, A. (2008). *Clickers, pedagogy and edtechtainment. Inside Higher Ed*, 20 June;. Available online (Retrieved November 10th, 2009): http://www.insidehighered.com/views/2008/06/20/groveman#Comments.

Guest, G., Bunce, A., & Johnson, L. (2006). How many interviews are enough? An experiment with data saturation and variability. *Field Methods*, 18, 59-82.

Guthrie, R.W., & Carlin, A. (2004). *Waking the dead: Using interactive technology to engage passive listeners in the classroom*. New York: Proceedings of the Tenth Americas Conference on Information Systems.

Haggis, T. (2003). Constructing images of ourselves? A critical investigation into 'approaches to learning' research in higher education. *British Educational Research Journal*, 29, 89-104.

Hake, R.R. (2008). *The case for classroom clickers – A response to Bugeja*. Available online (Retrieved November 5th, 2009):
http://www.physics.indiana.edu/~hake/CaseForClickersJ.pdf.

Hake, R. R. (1998). Interactive-engagement versus traditional methods: A six-thousand student survey of mechanics data for introductory physics courses. *American Journal of Physics*, 66, 64-74.

Hamilton, E., & Hurford, A. (2007). Combining collaborative workspaces with tablet computing: Research in learner engagement and conditions of flow. In *Proceedings of the 37th ASEE/IEEE Frontiers in Education Conference*. Milwaukee, Wisconsin: IEEE Press.

Hannula, M.S., Panziara, M., & Waege, K. (2009). *Affect and mathematical thinking.* Working Group 1, CERME 6, Lyon, France.

Harrison, C., Comber, C., Fisher, T., Hawe, K., Lewin, C., et al. (2002). *ImpaCT2: The Impact of Information and Communication Technologies on Pupils Learning and Attainment. ICT in Schools Research and Evaluation Series No.7.* Coventry: DfES-Becta.

Hawkes, T., & Savage, M. D. (2000). *Measuring the Mathematics Problem.* London: Engineering Council.

Hazel, E., Prosser, M., & Trigwell, K. (2002). Variation in learning orchestration in university biology courses. *International Journal of Science Education*, 24, 737-751.

Heid, K. (2003). *Research on technology and the teaching and learning of mathematics*. Available online (Retrieved May 10th 2010):
http://cltnet.org/archive/dfgnsf/docs/HeidDFGNSFWorkshop.pdf.

Helme, S., & Clarke, D. (2001). Identifying cognitive engagement in the mathematics classroom. *Mathematics Education Research Journal, 13,* 133–153

Hennessy, S., Fung, P. & Scanlon, E. (2001). The role of the graphic calculator in mediating graphing activity. *International Journal of Mathematical Education in Science and Technology*, 32 (2), 267-290.

Hewitt, D. (2009). The role of attention in the learning of formal algebraic notation: the case of a mixed ability Year 5 using the software grid algebra. In Joubert, M. (Ed.), *Proceedings of the British Society for Research into Learning Mathematics,* 29(3), 43-48.

Hibberd, S., & Mustoe, L. (2000). *Mathematical education of engineers III: Proceedings of the third conference*. Southend, UK: Institute of Mathematics and its Applications.

Highfield, K., & Goodwin, K. (2008). A review of recent research in early mathematics learning and technology. In Goos, M., Brown. R., & Makar, K. (Eds.), Proceedings of the 31st Annual Conference of the Mathematics Education Research Group of Australasia. *Navigating Currents and Charting Directions*, 1, 259–264. Brisbane: MERGA.

Hirsh, J. B., & Inzlicht, M. (2010). Error-related negativity predicts academic performance. *Psychophysiology*, *47* (1), 192-196.

Hoyles, C., & Lagrange, J.-B. (2008) (Eds.). *Mathematics education and technology – rethinking the terrain. The 17th CMI study*. Heidelberg: Springer.

Hoyles, C. & Noss, R. (2003). What can digital technologies take from and bring to research in mathematics education? In: Bishop, A.J., Clements, M.A., Keitel, C., Kilpatrick, J., & Leung, F.K.S. (Eds.), *Second International Handbook of Research in Mathematics Education* (pp.323-349). Dordrecht: Kluwer.

ICME 10 (2008). In Niss, M., & Emborg, E. (Eds.) *Proceedings of the Tenth International Congress on Mathematical Education (p149)*. Roskilde: IMFUFA, Roskilde University.

JISC (2007). *In their own words: Exploring the learner's perspective on e-learning.* Available online (Retrieved September 10th, 2009): http://www.jisc.ac.uk/media/documents/programmes/elearningpedagogy/iowtext.doc.

Johnson, M. & Robson, D. (2008). Clickers, student engagement and performance in an introductory economics course: A cautionary tale. *Computers in Higher Education Economics Review*, 20 (1), 4-12.

Jones, M., Marsden, G., & Gruitjers, D. (2006). In Banks, D.A. (Ed.), *Audience Response Systems in Higher Education: Applications and Cases* (pp. 359-372). Hershey, PA: Idea Group Inc.

Kaleta, R., & Joosten, T. (2007). Student response systems: A University of Wisconsin study of clickers. *ECAR Research Bulletin*, 2007 (10).

Kaput, J., & Roschelle, J. (1999). The mathematics of change and variation from a millennial perspective: New content, new context. In Hoyles, C. Morgan, C., & Woodhouse, G. (Eds.), *Rethinking the Mathematics Curriculum*, 155-170. London: Falmer Press.

Kelle, U. (2004). Computer-assisted analysis of qualitative data. In Flick, U., Kardoff, V.E., & Steinke, I. (Eds.), *A companion to qualitative research,* 276-293. London: Sage.

Kennewell, S. (2006.) *Reflections on the interactive whiteboard phenomenon: A synthesis of research from the UK*. In: AARE conference, Adelaide, Australia.

Kent, P., & Noss, R. (2003). *Mathematics in the university education of engineers (A report to The Ove Arup Foundation*). London: The Ove Arup Foundation. Available online (Retrieved January 6th, 2010): http://ovearupf.myzen.co.uk/files/Kent-Noss-report.pdf.

King, S.O. (2007). *Usability evaluation of 2D visual tagging systems*. MSc Thesis, University of Cape Town.

King, S.O., & Robinson, C.L. (2009a). *Formative teaching: A conversational framework for evaluating the impact of response technology on student experience, engagement, and achievement*. The 39th Annual Frontiers in Education (FIE) Conference, San Antonio, Texas.

King, S.O., & Robinson, C.L. (2009b). Pretty lights' and maths! Increasing student engagement and enhancing learning through the use of electronic voting systems. *Computers & Education*, 53(1), 189-199.

King, S.O., & Robinson, C.L. (2009c). Staff perspectives on the use of technology for enabling formative assessment and automated student feedback. *ITALICS,* 8(2).

King, S.O., Robinson, C.L., Davis, L., Croft, A.C., & Ward, J.P. (2008). *Staff perceptions of the one tablet mathematics classroom*. The 11th International Congress on Mathematical Education (ICME11), Topical Study Group 5 (TSG 5), Monterrey, Mexico.

Kolb, D.A. (1984). *Experiential learning: experience as the source of learning and development*. Englewood Cliffs, NJ: Prentice-Hall.

Krapp, A., Hidi, S., & Renninger, K. A. (1992). Interest, learning, and development. In K. A. Renniger, S. Hidi, & A. Krapp (Eds.), *The role of interest in learning and development* (pp. 3–27). Hillsdale, NJ: Lawrence Erlbaum.

Kulik, J. A. (1994). Meta-analytic studies of findings on computerized instruction. In E. Baker & H. O'Neil (Eds.), *Technology assessment in education and training* (pp. 9–33). Hillsdale, NJ: Lawrence Erlbaum Associates.

Kvale, S. (1996). *InterViews: An introduction to qualitative research interviewing.* London: Sage.

Laborde, C., & Strasser, R. (2010). Place and use of new technologies in the teaching of mathematics: ICMI activities in the past 25 years. *ZDM Mathematics Education*, 42, 121-133.

Laurillard, D. (2008). Evolving a vision for technology-enhanced learning. *Keynote Presentation, Networked Learning Conference,* Halkidiki, Greece.

Laurillard, D. (2002). *Rethinking university teaching: A conversational framework for the effective use of learning technologies* (2nd ed.). London: RoutledgeFalmer.

Lavicza, Z. (2010). Integrating technology into mathematics teaching at university level. *ZDM Mathematics Education*, 42,105-119.

LeCompte, M., & Preissle, J. (1993). *Ethnography and qualitative design in educational research* (2nd ed.). London: Academic Press.

Lincoln, Y., & Guba, E. (1985). *Naturalistic inquiry*. New York: Sage.

Linder, C., & Marshall, D. (1997). Introducing and evaluating metacognitive strategies in large class introductory physics teaching. In Rust, C. (Ed.), *Improving student learning: improving students as learners*. Oxford: Oxford Centre for Staff and Learning Development.

Lomen, D. O., & Robinson, M. K. (2004). *Using ConcepTests in single and multivariable calculus*. Paper presented at the 16th Annual International Conference on Technology in Collegiate Mathematics, Chicago, Illinois.

MacGeorge, E. L., Homan, S. R., Dunning, J. B. Jr, Elmore, D., Bodie, G. D., Evans, E. et al (2008). Student evaluation of audience response technology in large lecture class. *Educational Technology Research and Development*, 56, 125–145.

Marks, H. M. (2000). Student engagement in instructional activity: Patterns in the elementary, middle, and high school years. *American Educational Research Journal, 37,* 153–184.

Marshall, D. & Case, J. (2005). Approaches to learning' research in higher education: a response to Haggis. *British Educational Research Journal,* 31(2), 256-267.

Marton, F., & Saljo, R. (1984). Approaches to learning. In Marton, F., Hounsell, D. & Entwistle, N. (Eds.), *The experience of learning*. Edinburgh: Scottish Academic Press.

Marton, F. & Saljo, R. (1976b). On qualitative differences in learning: II. Outcome as a function of the learner's conception of the task. *British Journal of Educational Psychology*, 46, 115-127.

Marton, F. & Saljo, R. (1976a). On qualitative differences in learning: I. Outcome and process. *British Journal of Educational Psychology*, 46, 4-11.

Mason, J. (1989). Mathematical abstraction as the result of a delicate shift of attention. *For the learning of mathematics,* 9(2)**,** 2-8.

Mazur, E. (1997). *Peer instruction: A user's manual*. Upper Saddle River, NJ: Prentice Hall.

McLeod, D. B. (1992). Research on Affect in Mathematics Education: A Reconceptualization. In Douglas A. G. (Ed.), *Handbook of Research on Mathematics Teaching and Learning* (pp. 575-596). New York: Macmillan.

Meyer, J. H. F. (2000). The modelling of 'dissonant' study orchestration in higher education. *European Journal of Psychology of Education*, 15, 5-18.

Middendorf, J., & Kalish, A. (1996). The "change-up" in lectures. *The National Teaching and Learning Forum*, 5(2), 1-5.

Miller, R. B., Greene, B. A., Montalvo, G. P., Ravindran, B., & Nichols, J. D. (1996). Engagement in academic work: The role of learning goals, future consequences, pleasing others, and perceived ability. *Contemporary Educational Psychology, 21,* 388–422.

Nagel, D. (2007). *DOE software study: Are the numbers flawed?* Available online (Retrieved May 14th, 2010): http://thejournal.com/Articles/2007/04/06/DOE-Software-Study-Are-the-Numbers-Flawed.aspx?p=1.

Nicol, D., & Boyle, J. (2003). Peer instruction versus class-wide discussion in large classes: A comparison of two interaction methods in the wired classroom. *Studies in Higher Education*, 28(4), 457-473.

Nicol, D., & MacFarlane-Dick, D. (2006). Formative assessment and self-regulated learning: A model and seven principles of good feedback practice. *Studies in Higher Education* 31(2): 199-218.

NMAP - National Mathematics Advisory Panel (2008). *Foundations for success: The final report of the National Mathematics Advisory Panel*. Washington, DC: Department of Education.

Novak, G., Patterson, E., Gavrin, A., & Wolfgang, C. (1999). *Just-in-time teaching: Blending active learning and web technology*. Upper Saddle River, NJ: Prentice–Hall.

NRC - National Research Council (2001). *Adding it up: Helping children learn mathematics*. In Kilpatrick, J., Swafford, J., & Findell, B. (Eds.), Mathematics Learning Study Committee, Center for Education, Division of Behavioral and Social Sciences and Education. Washington, DC: National Academy Press.

Oblinger, D. (2008). Growing up with Google - What it means to education. *Emerging technologies for learning*, 3. Coventry: Becta.

Olive, J., & Makar, K. (2009). Mathematical knowledge and practices resulting from access to digital technologies. In Hoyles, C., & Lagrange, J.-B. (Eds.). *Mathematics education and technology – rethinking the terrain. The 17th CMI study*. Heidelberg: Springer.

Palazzo, D.J., Lee, Y.J., & Pritchard, D. (in press*). Self-reported academic dishonesty survey, interviews, and comparison with detected rate of homework copying*.

Palazzo, D.J., Lee, Y.J., Warnakulasooriya, R., & Pritchard, D. (2010). Patterns, correlates, and reduction of homework copying. Phys. Rev. St Phys. Educ. Res., (6), 010104+.

Pashler, H., McDaniel, M., Rohrer, D., & Bjork, R. (2008). Learning styles: Concepts and evidence. *Psychological Science in the Public Interest*, *9* (3), 105-119.

Pegg, J., & Tall, D. O. (2005). The fundamental cycle of concept construction underlying various theoretical frameworks. *International Reviews on Mathematical Education (ZDM)*, *37*(6), 468-475.

Perks, P. (1995). Calculators and young children: A bridge to number? In L.Burton & B. Jaworski (Eds.), *Technology in Mathematics Teaching*. Bromley: Chartwell-Bratt.

Pintrich, P.R., Conley, A.M., & Kemplet, T.M. (2003). Current issues in achievement goal theory and research. *International Journal of Educational Research* 39(4): 319-337.

Pintrich, P. R., & De Groot, E. (1990). Motivated and self-regulated learning components of academic performance. *Journal of Educational Psychology, 82,* 33–40.

Pintrich, P., & Garcia, T. (1991). Student goal orientation and self-regulation in the college classroom. In Maehr, M., & Pintrich, P. (Eds.), *Advances in motivation and achievement: Goals and self-regulatory processes*, 7, 371–402. Greenwich, CT: JAI Press.

Pintrich, P. (2000c). The role of goal orientation in self-regulated learning. In Boekaerts, M., Pintrich, P., & Zeidner. M. (Eds.), *The handbook of self-regulation: Theory, research, and applications* (pp. 451–502). San Diego: Academic Press.

Pintrich, P. (2000b). Multiple goals, multiple pathways: The role of goal orientation in learning and achievement. *Journal of Educational Psychology*, 92, 544–555.

Pintrich, P. (2000a). An achievement goal theory perspective on issues in motivation terminology, theory, and research. *Contemporary Educational Psychology*, 25, 92–104.

Pintrich, P., & Schunk, D. (2002). *Motivation in education: Theory, research and applications*. Upper Saddle River, NJ: Prentice-Hall Merrill.

Pólya, G. (1966). *Let Us Teach Guessing*. Washington, DC: MAA Video.

Pólya, G. (1954). *Mathematics and Plausible Reasoning: Patterns of Plausible Inference* (Volume II). Princeton, New Jersey: Princeton University Press.

Prosser, M., & Trigwell, K. (1999). Understanding learning and teaching: The experience in higher education. Buckingham: Open University Press.

Proulx, T., & Heine, S. J. (2009). Connections from Kafka: Exposure to meaning threats improves implicit learning of an artificial grammar. *Psychological Science*, *20* (9), 1125-1131.

Ramsden, P. (1992). *Learning to teach in higher education*. London: Routledge.

Ramsden, P. (1988). Studying learning: improving teaching. In Ramsden, P. (Ed.), *Improving learning: new perspectives*. London: Kogan Page.

Ramsden, P. (1987). Improving teaching and learning in higher education: The case for a relational perspective. *Studies in Higher Education*, 12, 274–286.

Ramsden, P. (1984). The context of learning. In Marton, F., Hounsell, D., & Entwistle, N. (Eds.), *The experience of learning*. Edinburgh: Scottish Academic Press.

Roschelle, J., Penuel, W.R., & Abrahamson, L. (2004). *Classroom response and communication systems: Research review and theory*. Paper presented at the Annual Meeting of the American Educational Research Association, San Diego, CA.

Russell, M. (2008). Using an electronic voting system to enhance learning and teaching. *Engineering Education: Journal of the Higher Education Academy Engineering Subject Centre, 3*(2).

Sapsford, R., & Jupp, V. (1996). *Data collection and analysis*. London: Sage.

Sawyer, W.W. (1943). *Mathematician's delight*. Middlesex: Penguin Books.

Schacter, J. (1999). *The impact of education technology on student achievement: What the most current research has to say*. Santa Monica, CA: Milken Exchange on Education Technology.

Schacter, J., & Fagnano, C. (1999). Does computer technology improve student learning and achievement? How, when, and under what conditions? *Journal of Educational Computing Research,* 20, 329–43.

Shoaf-Grubbs, M.M. (1995). Research results on the effect of the graphic calculator on female students' cognitive levels and visual thinking. In Burton, L., & Jaworski, B. (Eds.), *Technology in Mathematics Teaching*. Chartwell-Bratt: Bromley.

Shulman, L.S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher*, (15), 4-14.

Simpson, V., & Oliver, M. (2007). Electronic voting systems for lectures then and now: A comparison of research and practice. *Australasian Journal of Educational Technology,* 23(2), 187-208.

Simpson, V. & Oliver, M. (2002). Using electronic voting systems in lectures. University College London (UCL) Internal report.

Sivin-Kachala, J. (1998). *Report on the effectiveness of technology in schools, 1990-1997*. Software Publisher's Association.

Skemp, R.R. (1989). *Mathematics in the primary school*. London: Routledge.

Skemp, R. R. (1976). Relational understanding and instrumental understanding. *Mathematics Teaching, 77*, 1-7.

Skemp, R. R. (1971). *The Psychology of Learning Mathematics*. Baltimore, MD: Penguin Books, Inc.

Sloane, F.C. (2008). Randomized trials in mathematics education: Recalibrating the proposed high watermark. *Educational Researcher*, 37, 624 - 630.

Smart, T. (1995). Visualisation, confidence and magic. In Burton, L., & Jaworski, B. (Eds.), *Technology in Mathematics Teaching*. Chartwell-Bratt: Bromley.

Snyder, B. R. (1971). *The hidden curriculum*. New York: Alfred A. Knopf.

Socol, I.D. (2008). *Who's behind the curtain?* Available online (Retrieved November 7th, 2009): http://speedchange.blogspot.com/2008/12/whos-behind-curtain.html.

Somekh, B., Haldane, M., Jones, K., Lewin, C., Steadman, S., et al. (2007). *Evaluation of the Primary Schools Whiteboard Expansion Project*. Coventry: Becta-DfES.

Stanley, L., & Temple, B. (1995). Doing the business? Evaluating software packages to aid the analysis of qualitative data sets. *Studies in Qualitative Methodology*, 5, 169-97.

Stavy, R., & Tirosh, D. (2000). *How students (mis)understand science and mathematics: Intuitive rules*. New York: Teachers College Press.

Symmonds, R.J. (2009). *Evaluating student engagement with mathematics support*. PhD thesis, University of Loughborough.

Tall, D. (in press). *How humans learn to think mathematically*. [38]Excerpts available online (Retrieved January 21st, 2010):
http://www.warwick.ac.uk/staff/David.Tall/drafts.html.

Tall, D. (2008). The transition to formal thinking in mathematics. *Mathematics Education Research Journal,* 20 (2), 5-24

Tirosh, D., & Tsamir, P. (2004). What can mathematics education gain from the conceptual change approach and what can the conceptual change approach gain from its application to mathematics education? In Verschaffel, l., & Vosniadou, S. (Eds), *Extending the conceptual change approach to mathematics learning and teaching. Learning and Instruction*, doi: 10.1016/j.learninstruc.2004.06.017.

Underwood, J. (2009). *The impact of educational technology: A review of the evidence of the impact of digital technologies on formal education*. Coventry: Becta.

Underwood, J., Baguley, T., Banyard, P., Dillon, G., Farrington-Flint, L., & Hayes, M., et al., (2009). *Impact 2008*. Coventry: Becta.

USDoE (2009). *Evaluation of Evidence-Based Practices in Online Learning: A Meta-Analysis and Review of Online Learning Studies*. Washington, D.C.: . U.S. Department of Education, Office of Planning, Evaluation, and Policy Development.

Vermetten, Y. J., Vermunt, J. D., & Lodewijks, H. G. (2002). Powerful learning environments? How university students differ in their response to instructional measures. *Learning and Instruction*, 12(3), 263–284.

---

[38] I was provided with a draft of the whole book by the author.

Volet, S. E., & Chalmers, D. (1992). Investigation of qualitative differences in university students' learning goals, based on an unfolding model of stage development. *British Journal of Educational Psychology*, 62, 17-34.

Watson, A., De Geest, E., & Prestage, S. (2003). *Deep progress in mathematics: Report of the improving attainment in mathematics project*. Oxford: University of Oxford, Department of Educational Studies.

Watson, A., & Mason, J.H. (2002). Student-generated examples in the learning of mathematics. *Canadian Journal of Science, Mathematics and Technology Education* 2(2), 237-249.

Webb, G. (1997). Deconstructing deep and surface: Towards a critique of phenomenography. *Higher Education,* 33, 195-212.

Weinstein, C., & Mayer, R. (1986). The teaching of learning strategies. In Wittrock, M.C. (Ed.), *Handbook of research on teaching and learning* (3rd ed., pp. 315–327). New York: Macmillan.

Wenglinsky, H. (1998). *Does it compute? The relationship between educational technology and student achievement in mathematics*. Educational Testing Service Policy Information Center.

Wilson, K. (2009). Alignment between teachers' practices and pupils' attention in a spreadsheet environment. In Tzekaki, M., Kaldrimidou, M., & Sakonidis, H. (Eds.), *Proceedings of the 33rd Conference of the International Group for the Psychology of Mathematics Education*, 5, 353-360.

Wilson, K., & Korn, J. H. (2007). Attention during lectures: Beyond ten minutes. *Teaching of Psychology,* 34 (2), 85–89.

Wilson, M. (2006). Evaluation of classroom response systems/voting tools. Falkirk, Council Educational Services, Falkirk, Scotland. Available online (Retrieved August 20th, 2010): http://www.reap.ac.uk/public/Resources/Falkirk_EVS_Evaluation.pdf.

Wolters, C., Yu, S., & Pintrich, P. (1996). The relation between goal orientation and students' motivational beliefs and self-regulated learning. *Learning and Individual Differences*, 8, 211–238.

Zaslavsky, O. (1995). Open-ended tasks as a trigger for mathematics teachers' professional development. *For the Learning of Mathematics,* 15(3), 15 – 20.

Zhu, E. (2007). What do students appreciate most about clickers? Center for Research on Learning and Teaching, Occasional Papers, 22. Available online (Retrieved December 5th, 2009): http://www.crlt.umich.edu/publinks/CRLT_no22.pdf.

Zimmaro, D.M. (2004). *Writing good multiple-choice exams*. Measurement and Evaluation Center, University of Texas, Austin. Available Online (Retrieved November 15th, 2009):

http://www.utexas.edu/academic/mec/research/pdf/writingmcexamshandout.pdf.

APPENDIX A: EVS QUESTIONNAIRE

EVS Use for Mathematics Teaching-Britain

Mathematics
Education Centre MEC

| My Surveys | Create Survey | My Details | Account Details | Account Users |

Introduction

Hello, my name is Samuel O. King and I am conducting research into the effectiveness of new technologies for teaching and learning Mathematics.

The purpose of this questionnaire is to collect information about staff experiences regarding the use of Electronic Voting Systems (EVS) for teaching mathematics at university level. Please be assured that all data is confidential and your anonymity will be preserved throughout.

Background

1. Name (optional) / University / University Maths' Teaching Experience
e.g. Samuel King / Loughborough / 5 years *(Optional)*

2. Which class(es) do you teach using EVS, and how many students are in each class? e.g. Mathematics for Engineers (1st Year) - 95 students;
Linear Algebra (2nd Year) - 56 students

3. Which of the following accurately describes your experience with EVS use?

- ◯ Have used EVS only once
- ◯ Have used EVS 2-3 times
- ◯ Have used EVS regularly for an academic semester
- ◯ Have used EVS regularly for an academic year
- ◯ Have used EVS regularly for 2-3 years
- ◯ Have used EVS regularly for >3 years
- ◯ Other *(please specify)*:

You may use the 'other' column to explain your answer.

4. How did you find out about EVS, and what made you decide to start using it?

5. Which EVS system(s) have you used or currently use?
   (select all that apply)

☐ TurningPoint ResponseCard XR
☐ TurningPoint ResponseCard RF (Radio Frequency)
☐ TurningPoint ResponseCard IR (Infra Red)
☐ InterWrite (PRS)
☐ InterWrite (Cricket)
☐ Classroom Performance System (CPS)
☐ Promethean ActivExpression
☐ Promethean ActiVote
☐ Other *(please specify)*:

Does this system allow open-ended numerical or text entry?
◯ Yes ◯ No
◯ Other *(please specify)*:

6. At your institution, who is responsible for the purchase of the EVS handsets, which students use to submit their answers in class, and the receiver, which enables a lecturer to collate student submissions?
   (select all that apply)

[More Info]

☐ Students buy their own handsets
☐ Students don't buy - they are given handsets to use per lecture
☐ Students don't buy - they borrow the handsets for a semester/year
☐ Lecturers buy receiver only
☐ Lecturers buy both receiver and handset for use in lectures
☐ Lecturers don't buy either the receiver or handset - the University does
☐ Other *(please specify)*:

You may use 'other' to explain your answer.

EVS Questions and Pedagogical Considerations

7. How did you select the questions used during lectures?
   (select all that apply)

☐ From past (course, test, etc) questions
☐ From a designated (e.g. online or offline) resource
☐ Created new i.e. questions are lecturer's own creation

338

☐ A combination of the methods above
☐ Other *(please specify)*:

[text box]

You may use the 'other' column to elaborate on your answer.

8. What were your guiding principles or goals in choosing/setting EVS questions?

[text box]

9. How many EVS questions do you typically use per lecture?

○ 1-2 ○ 3-4 ○ 5-6 ○ >6
○ Other *(please specify)*:

[text box]

10. When during a lecture do you use the questions (e.g. beginning, middle or towards the end of lecture; or questions paced throughout lecture), and why?

[text box]

11. For the statements below, please select all that apply:
   (select all that apply)

☐ Have used EVS for only multiple choice questions (MCQs)
☐ Have used EVS for both MCQs and open-ended questions
☐ Have used (EVS) questions for formative assessment only
☐ Have used EVS for both formative and summative assessments
☐ Have used EVS to formally register attendance
☐ Other *(please specify)*:

[text box]

You may use the 'other' box to explain your selections.

12. Could you describe the types of questions you have used with EVS (e.g. to test recall, to probe student understanding, ice breakers, etc)?

```
```

13. How do you evaluate whether a question has been effective?
(*select all that apply*)

☐ When there is good spread in terms of the range of student response
☐ When more students get the answer right
☐ When more students get the answer wrong
☐ When student response leads to the identification of problem areas
☐ When student response produces unexpected results
☐ Other (*please specify*):

```
```

You may use the 'other' column to elaborate on your answer.

14. Compared to classes where EVS was not used, how much (extra) time did you spend collecting, designing or creating the EVS questions used in classes where EVS was used?

	A great deal of time (i.e. significant extra time spent)	A moderate amount of time (i.e. extra time spent not very significant)	Minimal time increase (i.e. no significant difference in time spent)	Other (*please specify*)
a. Early in Semester	○	○	○	○
b. Later in Semester	○	○	○	○

15. Did you struggle to cover the required (syllabus) material in lectures due to the increased time pressure as a result of EVS use?

○ Yes, I could not cover all the required material
○ Yes, but I managed to somehow cover the required material
○ Yes, so I focused on the most essential aspects of the module
○ No, I did not struggle with covering the required material
○ Other (*please specify*):

[text box]

16. Which (mathematical) topics have you found EVS most beneficial or useful for teaching?

[text box]

17. Have you obtained any unexpected results or made any remarkable observations about the impact of EVS on your teaching or student learning of mathematics?

[text box]

Please use the text box to elaborate on your answer.

18. Based on your experience, please rate the value of EVS as a tool for the teaching of university mathematics:

○ Strongly advantageous ○ Advantageous ○ Undecided ○ Disadvantageous ○ Strongly disadvantageous

Student Experience

19. Are students in your class usually encouraged to discuss their answers before or after voting, or engage in peer discussion when EVS is used? *(select all that apply)* [More Info]

☐ Yes ☐ No
☐ Other *(please specify)*:

[text box]

You may use 'other' to explain your answer.

20. How would you say that students have responded to the use of EVS?

○ They have shown very positive attitudes towards EVS use
○ They have shown positive attitudes towards EVS use
○ They have been indifferent towards EVS use
○ They have shown negative attitudes towards EVS use
○ They have shown very negative attitudes towards EVS use
○ Other *(please specify)*:

[text box]

21. Based on your experience of EVS use (i.e. class observation and % of students responding), would you say you have noticed any impact (or otherwise) of EVS use on student participation rates in class?
 (select all that apply)

☐ EVS use has significantly increased student participation

☐ EVS use has led to a minor increase in student participation

☐ EVS use has had no impact on student participation

☐ EVS use had led to a minor decline in student participation

☐ EVS use had led to a significant decline in student participation

☐ Other *(please specify)*:

You may use 'other' column to explain your answer.

22. Based on your experience of EVS use, would you say you have noticed any impact (or otherwise) of EVS use on student achievement, as measured by grades on formal (summative) assessments?
 (select all that apply)

☐ EVS use has little or no effect on overall academic performance

☐ EVS use has contributed to a decline in overall academic performance

☐ EVS use has led to improvement in overall academic performance

☐ I do not have sufficient data to verify this

☐ Other *(please specify)*:

You may use 'other' column to explain your answer.

23. Based on your experience, what would you say has been the impact (or otherwise) of EVS use on the mental processing or problem solving of in-class material during lectures?

24. Based on your experience of EVS use, would you say the use of EVS reinforces (or otherwise), in students, a particular learning style or approach to studying mathematics?
 (select all that apply)

☐ EVS use tends to reinforce a surface learning approach to maths

☐ EVS use tends to reinforce a deep learning approach to maths

☐ It depends on the type of questions used

☐ It depends on staff pedagogical styles or practises

☐ It depends on the individual student

☐ I do not have sufficient data to verify this

☐ Other *(please specify)*:

342

```
┌─────────────────────────────────┐
│                                 │
│                                 │
│                                 │
└─────────────────────────────────┘
```

25. Could you describe the kind(s) of feedback you have received from student answers to EVS questions?
   (select all that apply)

☐ Identification of common student errors or misconceptions
☐ Identification of components of topics students find difficult
☐ Mapping of overall student strengths on a topic by topic basis
☐ Ease/Difficulty level of a question(s)
☐ Validation of the effectiveness or otherwise of question(s)
☐ Student understanding of previous lessons
☐ Evidence on how to effectively introduce a topic
☐ Other *(please specify)*:

```
┌─────────────────────────────────┐
│                                 │
│                                 │
│                                 │
└─────────────────────────────────┘
```

26. Have you incorporated this student feedback from EVS use into your teaching?
   (select all that apply)

☐ No   ☐ Yes
☐ Other *(please specify)*:

```
┌─────────────────────────────────┐
│                                 │
│                                 │
│                                 │
└─────────────────────────────────┘
```

You may use the 'other' column to explain how you have incorporated feedback from students into your teaching.

27. Could you describe the kind(s) of feedback you provide to students after they have submitted their answers to the EVS questions used in class?
   (select all that apply)

☐ A step-by-step solution of the problem
☐ Explanation of why the alternative options provided are incorrect
☐ Highlight of question's importance to overall topic and course objectives
☐ Discussion of the distribution of students' correct and incorrect answers
☐ Other *(please specify)*:

```
┌─────────────────────────────────┐
│                                 │
│                                 │
│                                 │
└─────────────────────────────────┘
```

28. In general, are there any differences between the feedback provided in a typical mathematics lecture where EVS is used and one in which EVS is

not used?

```
[                    ]
```

29. In general, in what ways have the use of EVS, including feedback from students, influenced your teaching?
  (select all that apply)

☐ Focused more on problem areas
☐ Revised course/module curriculum
☐ Use of questions helps delineate lecture into discrete segments
☐ Enhanced skills for creating and using questions
☐ Identification of student misconceptions and/or errors
☐ Increased lecturer-student interactivity in my lectures
☐ Changed some other teaching style/practice
☐ Other *(please specify)*:

```
[                    ]
```

You may use 'other' to elaborate on your answer.

Reflection

30. What would you say are the barriers to maximising the use and effectiveness of EVS as a tool for university mathematics' teaching?

```
[                    ]
```

31. What would you say are the key requirements for maximising the use and effectiveness of EVS as a tool for university mathematics' teaching?

```
[                    ]
```

32. Based on my experience, EVS is a tool that can significantly enhance the teaching of university mathematics.

◯ Strongly agree   ◯ Agree   ◯ Undecided   ◯ Disagree   ◯ Strongly disagree

33. Based on your experience, would you continue to use EVS for future lectures/academic sessions?

◯ Yes, with no modification of the current EVS set-up   ◯ Yes, with modification of the current EVS set-up
◯ I am indifferent   ◯ I am not sure   ◯ No, I have stopped/would definitely stop using EVS
◯ Other *(please specify)*:

34. Do you have any other comments? *(Optional)*

Continue >   Check Answers & Continue >

APPENDIX B: STAFF RESPONDENT VALIDATION

Dear Respondent,

Hope you are doing well. You might recall that about a year ago, you graciously completed an online survey about the use of Electronic Voting Systems (EVS) for mathematics teaching. I have now concluded data analysis and interpretation of the survey results. I am therefore attaching with this mail a copy of my initial report on the findings. This report is a draft chapter of my (PhD) thesis, hence the references to sections and chapters. I hope you will find the report useful. I have also included below a summary of the findings. In addition, I am attaching a document containing your responses to the survey questions.

I will appreciate it if you could provide me with feedback or comments on aspects of the report that you disagree/agree with. I will also welcome any suggestions as to how the report may be improved or strengthened.

Thank you very much.

Regards,

Sam

Samuel O. King

Mathematics Education Centre

Loughborough University

Loughborough LE11 3TU

Tel: 01509 22 2877

DISCUSSION AND CONCLUSION

In this chapter I have presented the methodology, results and analysis of data from a survey study designed with a view to answering the research question, How has the use of EVS influenced university mathematics teaching? I have also illustrated how the

twin benefits of EVS use for teaching from literature, enhanced feedback and student engagement with learning may be explained through the conversational framework. Respondent submissions to similar items on the current survey show correspondence with submissions of respondents to the 2008 study. In this section, I will present the conclusions of the study.

First, a review of respondent submissions shows that academic staff were introduced to EVS and started using the system as a result of: Attending a presentation, its availability through a departmental or institutional initiative, or because a department expects its staff to use the tool. It is reasonable to expect that how the staff were introduced to EVS could influence its use. For example, if it were a departmental requirement that EVS be used for teaching mathematics, what effect would this have on staff attitudes towards EVS? On the other hand, staff who are free to choose to use or decide not to use EVS might be expected to display more positive attitudes and probably have more pedagogical principles for using EVS. However, the very limited evidence based on submissions from two respondents only (Table 2.25) suggests that making EVS use a departmental requirement might have a negative impact on the perception of EVS usefulness for mathematics teaching. This is an area for further study.

EVS is a tool that can significantly enhance university mathematics teaching	Presentation	Institutional Initiative	Course/Departmental Requirement
Strongly agree	2	2	
Agree	8	2	1
Undecided	0		
Disagree	0		
Strongly disagree	0		1

Table 2.25 A cross-tabulation of items 4 and 32 on the survey suggests that making EVS use mandatory might have a negative impact on the perception of EVS usefulness for mathematics teaching.

The four pedagogical principles enumerated by respondents as their rationale for using EVS – to receive feedback on student understanding, reinforce lecture material, enhance student engagement, and create good questions that would challenge students - seem to indicate that they are not using the technology just because it is available, but as a means for achieving specific teaching and learning objectives. Further, EVS is used exclusively for assessment for learning, although the majority of the questions used are MCQs. The average number of questions used per (mathematics) lecture is six, and these questions are structured such that they often serve as a way to maintain student attention during a lecture.

The EVS questions used are of four varieties: recall, application, and conceptual understanding questions, together with ice breakers. These questions are typically used to present problems requiring not more than two to three minutes, due to lecture time constraints. Moreover, EVS question usage typically does not involve the type of discussion described in Crouch and Mazur (2001), Beatty et al. (2006), and Nicol and Boyle (2004), although half of all respondents include a discursive component in their use of EVS. However, frequent questioning enhances student engagement with learning, as their use 'provide each student with a chance to think about and respond to a question before hearing other students' answers' (Bruff, 2009:199; see also Guthrie & Carlin, 2004; Frase et al., 1970). However, no impact on student achievement was reported.

A major component of EVS use is the provision of feedback, which might be viewed as consisting of two strands: Feedback that instructors receive from student answer submissions to EVS polling, and the feedback that instructors provide to students. The most important types of feedback that instructors claimed to have received from students are:

- Identification of common student errors or misconceptions;
- Identification of components of topics students find difficult;
- Student understanding of previous lessons;
- Ease/Difficulty level of a question(s).

Similarly, instructors provided the following types of feedback to students:

- Explanation of why the alternative options provided are incorrect;
- A step-by-step solution of the problem;
- Discussion of the distribution [or spread] of students' correct and incorrect answers.

Feedback from students provided instructors with a means of monitoring student comprehension both in real time and over the course of a module. Instructors are also able to use this student feedback to provide more targeted instructional measures. It is important to note that these two forms of feedback, which are an integral part of EVS-enabled lectures, are either largely absent from, or used infrequently in conventional mathematics lectures.

It is also important to note that EVS use is associated with a number of drawbacks. Time – to learn to use the system, create questions, use EVS in lectures and provide feedback, and 'tweak' questions in response to student feedback – is a concern. So also are EVS cost, the perception that EVS is often presented as the next 'big thing' in mathematics instruction, the perceived limited use of MCQs for promoting higher order learning, and the lack of (adequate) professional development opportunities for EVS users. Professional development is sine qua none for effective EVS use because experienced EVS users could, for example, share with their less experienced peers how they have been able to overcome time issues.

In conclusion, EVS is overwhelmingly (i.e. 93% of respondents) seen as a 'tool that can significantly enhance the teaching of university mathematics'. Similarly, EVS use is viewed as having the greatest impact on the ability of instructors to identify student misconceptions, which then enables instructors to focus more on the identified problem areas, with the EVS-induced question-and-answer sessions catalysing increased instructor-student interaction. Further, frequent questioning enhances student engagement with mathematical problem solving, especially in the classroom.

EVS is therefore a *tool* that can significantly enhance university mathematics teaching *and* learning. But it is imperative to note that EVS is only a tool, which if used well, could induce the teaching and learning benefits highlighted in this study. Ehrmann summed this up succinctly when he stated that EVS systems or clickers 'don't "cause" the learning, any more than the paper in a physics textbook or the blackboard behind the faculty member "cause" learning. But like them, clickers are a powerful tool in the proper circumstances and in the right hands' (Steve Ehrmann as quoted in Hake, 2008).

APPENDIX C: INTERVIEW PROTOCOL

Pre-Interview Questionnaire (1st set of questions)

NAME:
ID:

1. How proficient would you say you are in mathematics? Please circle one.

       Very good   Good   Average   Poor   Very poor

2. Before obtaining admission to Loughborough, Would you say you were looking forward to studying mathematics at university level? Please elaborate on your answer.

3. In what <u>way(s)</u> has the use of voting systems in MAB104 hindered or helped your learning/revision of Calculus?

4. What is your goal(s) for the MAB104 module e.g. Get a pass grade; Get a 100% score; Get a real understanding of course content; etc

5. What do you think you need to know or do to achieve your goal(s)?

6. Would you say the way or the rate you are learning in the MAB104 module is similar or different to the way or the rate you are learning in your other modules? Why is this so (Please explain)?

A. Review answers to Pre-Interview Questionnaire
(2nd set of questions)

B. EVS Questions *(3rd set of questions)*

  1. What are the disadvantages/problems (if any) of using handsets in lectures?

  2. What are the benefits (if any) of using handsets in lectures?

  3. Were there times you did not vote in class?

  4. Does EVS help you think more about a question or topic? How?

  5. How do you feel when an EVS question (i.e. because it's too hard or easy) puts you on the spot?

  6. Any other comments?

C. General Questions (*4th set of questions***)**

FEEDBACK: What happens when you get questions wrong? What do you (usually) do then or later?

What are your views about the feedback you get? Does it help you identify clearly where you went wrong, show you how you can get it right the next time, enough time for feedback?

Multiple select effect?

Response range effect?

Q1 (L1) (*5th set of questions***)**

What's your approach to solving maths questions? To EVS-type questions?

Do you recall this question?

How would you solve this problem?

What happens now when you see a question on double integrals?

Which aspect (if any) of the question did you have difficulty with?

There are 3 aspects:

  • 1st: '4' in Q1 represents height of surface
  • [dydx represents area of rectangle element in base dydx]
  • 2nd: Limits of integrals give area of base
  • 3rd: area of base + height = volume

The other way of getting it is to do the calculation straight

Sticking Point = 2 = 4 = plane

The students (probably) don't know 4 represents the plane i.e. Z = 4

- Module instructor had not yet taught them double integrals
- Students usually find complex functions difficult to integrate, so Q1 which was easy was selected for them to start with
- Instructor's intention was to get the students thinking whenever they encounter double integrals to try and relate them to a physical entity, e.g. Volume, Pressure, Moment of Inertia, etc

Q2 (L3)

Do you recall this question?

How would you solve this problem?

Which aspect (if any) of the question did you have difficulty with?

To see whether they understood the concept of what is happening so that they know what they need to do to reverse the order of integration

Q3 (L11)

Do you recall this question?

How would you solve this problem?

Did question prepare you for Fourier Series?

Which aspect (if any) of the question did you have difficulty with?

- Check that they could get equation of a straight line by determining M & C
- Realise there are 2 solutions i.e. multiple correct options (which helps safeguard against guesswork, makes students go through question one by one, thereby helping mental processing)
- The needed to get used to seeing the formula in the format shown to get prepared for Fourier Series

Q4 (L12) + Q5 (L13) + Q6 (L12)

Do you recall this question?

How would you solve this problem (e.g. did you sketch the curve)?

Did question prepare you for Fourier Series?

Which aspect (if any) of the question did you have difficulty with?

- A level but they need to get used to them

- 'n' throws them i.e. sin (n pi)
- Don't know /recall what the trigonometry/curve looks like
- Why are the other ones wrong?
- Did you sketch?

Q7 (L17) + Q8 (L17) + Q9 (L18) + Q10

Do you recall this question?

How would you solve this problem?

How has the question helped you with calculating and working with the different variables/notations in Differential Vector Calculus?

Which aspect (if any) of the question did you have difficulty with?

- Carol just gave them formula without telling them how to do it i.e. How to use formula and to calculate without being shown how
- Grad theta is going to have a vector outcome
- Partial Derivatives with unusual notations: ph, theta, I, j, k, etc
- Goal: So they can know what to do with Grad Theta whenever they see it
- Divergence: expansion or contraction

Q11 (L18) + Q12 (L19)

Do you recall this question?

How would you solve this problem?

Which aspect (if any) of the question did you have difficulty with?

Did you have enough time?

- Having multiple correct options eliminates guessing
- Have to work out if each statement is correct
- Did you have enough time?

Q14 (L6)

Do you recall this question?

How would you solve this problem?

Which aspect (if any) of the question did you have difficulty with?

- Cylindrical polar coordinates: dQdRdZ = volume

L19

Do you recall this question?

How would you solve this problem?

Which aspect (if any) of the question did you have difficulty with?

Did you recall that Div V = 0 for incompressible flow?

Q15 (L7)

Do you recall this question (not just from EVS, but from A level days at the time it was posed in class)?

How would you solve this problem?

Did question prepare you for Fourier Series?

Which aspect (if any) of the question did you have difficulty with?

- Knowledge of this (A Level) work needed for following lecture on Eigenvalues
- Many students got it wrong ; what do you do after?

Q16 (L7)

Do you recall this question?

How would you solve this problem?

Which aspect (if any) of the question did you have difficulty with?

- If the determinant of a simultaneous equation is = 0, then the equation has no solution

Q18 (L17)

Do you recall this question?

How would you solve this problem?

Which aspect (if any) of the question did you have difficulty with?

Were you able to make the connection between the question and the need for a constant based on the explanations that Carol had made in class?

- Contours are given by F (x,y) = constant
- i.e. x-2y = c [Please see the question tagged 'L17' on P365.]

APPENDIX D: INTERVIEWEE RESPONDENT VALIDATION

Hi K5,

Hope your preparations for the examinations are going well. You might recall that more than a year ago, I interviewed you about your learning experiences on the engineering mathematics module (MAB 104), and how the use of Electronic Voting Systems (EVS) may or may not have influenced your learning on that module. I have now analysed the data collected from your responses to the interview questions, and have categorised your approach to learning mathematics on the MAB 104 module as being characterised by a *Conceptual Deep* approach (see Table X below), based on the Approaches to Learning Theory (ALT) framework. To understand what this *Conceptual Deep* characterisation means, please see Table Y below.

In addition, Table X also includes a summary of the other characterisations (i.e. 'goal theory' and 'strategic approach') I made in respect to your approach to learning on the MAB 104 module. The descriptions provided in Table Y should be sufficient for these two other characterisations. However, do not hesitate to contact me if you require further clarifications, and I will send you relevant information about goal theory and the strategic approach construct. Also note that I have employed pseudonyms in my study to safeguard your privacy and assure confidentiality.

I would like to stress here that an individual student's approach to learning can vary from subject to subject, and at different times. What I have captured here was your approach to learning on the MAB104 module at that particular time. Please also note that your approach to learning (i.e. whether you are characterised as displaying a Surface, Procedural Surface, Procedural Deep or Conceptual Deep approach to learning) is not a reflection of your ability or potential, as a student in any of the categories could go on to (and have) become a distinguished engineer or mathematician. Moreover, the ALT framework is just one way of characterising learning approaches.

I would appreciate it if you could respond to this email, when you have a moment, to indicate your disagreement/agreement with your approach to learning characterisation, as depicted in this document, and also to include any other comments

you may have about this characterisation, or any other aspects of the MAB104 interview which you volunteered for early last year.

I am aware that you may not recall aspects of the interview due to the time lapse. I am therefore attaching your interview transcript with this mail, to help refresh your memory, in case there is anything you wish to refute, amend or make comments about.

If I do not hear from you, I would assume that this means you are in agreement with the conclusions I reached about your approach to learning mathematics on the MAB 104 module, based on your interview.

Thank you very much and good luck with your examinations.

 Regards,
Samuel King

Interviewee - K5	Characterisation
ALT	Conceptual Deep
Goal Theory	Mastery
Strategic Approach?	Yes

Table X Characterisation of K5's approach to learning mathematics.

APPROACH TO LEARNING MATHS based on the ALT framework	INTENTION (FOR LEARNING)	STRATEGY (FOR LEARNING)
SURFACE **(Performance goal)**	Reproduction or performance orientation *without* intention to understand	Rehearsal strategies – chiefly (surface) memorization of information or rote-learning, devoid of practise or problem solving
PROCEDURAL SURFACE **(Performance goal)**	Reproduction or performance orientation *without* intention to understand	Rehearsal strategies – chiefly problem solving
PROCEDURAL DEEP **(Performance goal)**	Reproduction or performance orientation *with* intention to understand; Focus on *subsequent understanding* (i.e. implicit meaning or understanding orientation)	Rehearsal strategies predominate (although both rehearsal and elaboration strategies are present)
CONCEPTUAL DEEP **(Mastery goal)**	Mastery, meaning or understanding orientation, with focus on *concurrent understanding*	Elaboration strategies predominate (although both rehearsal and elaboration strategies are present)
STRATEGIC APPROACH	Perform well on relevant assessment measure	Review of past examination papers, focus on cues from instructor about which aspects of module content to focus on for assessments, rehearsal strategies

Rehearsal strategies are characterised by: Identifying and memorising calculation methods for solving problems; Learning by repetition and memorisation of formulae and simple algorithms; To be able to repeat formulae and use algorithms in tests/examinations, effort-avoidant strategies that maximize short term retention of information….

Elaboration strategies are characterised by: Relating of formulae to each other, or parts of algorithms to other parts; Working through problems and consulting textbook, puzzling over gaps in understanding; Relating of learning tasks to their underlying concepts or theory i.e. relating new information to existing knowledge, comprehension monitoring, organization, regulating attention, persistence….

Table Y A comprehensive and expanded guide showing the criteria employed in characterising student approaches via the ALT framework (Case & Marshall, 2004; Pintrich, Conley & Kempler, 2003).

APPENDIX E: INTERVIEWEE CONSENT AND COMPENSATION

CONSENT FORM

Hello, my name is Samuel King, and I am conducting research into the effectiveness of new technologies in teaching and learning Mathematics.

The purpose of this interview session is to collect information with regards to the use of Electronic Voting Systems (EVS) in MAB 104, the handsets that you use to respond to questions in class. Your perceptions and opinions are important to us, so that we could assess the effectiveness of EVS use in Mathematics lectures. Please be assured that all data is confidential and your anonymity will be preserved throughout.

We would also like to inform you that this session would be recorded on video and audio. However the recording will not proceed without your express permission. You are also at liberty to discontinue with the interview session at any point, as participation is entirely voluntary. This is to reiterate that all data collected would be held anonymously and securely, based on the relevant Data Protection provisions. Moreover, no personal data (apart from name and student ID) is asked for, and all data will be treated confidentially. Survey results and feedback will be reviewed within the University, and aggregate data may be retained to benchmark future surveys.

Please sign below to indicate your assent to the principles guiding the conduct of this interview session as stated above.

Thank you.

Full Name	Signature	Date

COMPENSATION FORM

Please sign below to indicate that you have received a £10 compensation for time spent in the interview session for MAB104.

Full Name	Signature	Date

APPENDIX F: MODULE SPECIFICATION

CIS Portal - Module Specification WP5015

09MAB104 Engineering Mathematics 3

Principally taught by	School of Mathematics
Modular weight	10
ECTS Credit	5
Credit Level	5
Exam weighting	80
Prereq modules	MAA104(E) and MAA204(E)
Availability	Module is available to students meeting pre-requisites but only if listed in their Programme Regulations.
Responsible Examiner	Dr CL Robinson
Delivery Period	Semester 1

CONFIDENTIAL

Aims
The aim of this module is:
- to cover adequately those mathematical topics which are fundamental to all engineering disciplines. An over-rigorous approach is avoided.

Intended Learning Outcomes
On completion of this module students should be able to:

Knowledge and Understanding
- know how to use double/triple integrals to find volumes, masses, centres of gravity and moments of inertia;
- know some of the basic results of vector field theory including the divergence theorem and Stokes' theorem;
- understand how eigenvalue techniques can be used to convert matrices to diagonal form and solve coupled systems of ordinary differential equations;
- understand how an arbitrary periodic function can be expressed as a sum of sinusoidal components of different frequencies;
- know how to apply some of the techniques learnt to simple engineering problems;

Subject-specific Skills
- evaluate double integrals in cartesian and plane polar coordinates;
- evaluate triple integrals in cartesian, cylindrical and spherical polar coordinates;
- evaluate the gradient of a scalar function;
- evaluate the divergence and curl of a vector field;
- evaluate simple line integrals;
- identify conservative vector fields and find the associated scalar potential function;
- evaluate simple surface integrals;
- find the eigenvalues and eigenvectors of simple matrices and the corresponding modal matrix;
- find the trigonometric Fourier series of simple piecewise smooth functions;
- find half range Fourier sine and cosine expansions;

General Skills
- manage time effectively.

Content

Fourier Series. Eigenvalues/Eigenvectors. Multiple Integration. Vector Field Theory. (Divergence and Stokes' Theorems).

Method of Teaching, Learning and Assessment

Total student effort for the module: 100 hours on average.

Teaching & Learning:
A combination of 24 one-hour lectures and 12 one-hour tutorials with the remaining time for private study, working on problem sheets and revision for exam.

Assessment:
Coursework - (2 multiple choice in-class tests) (10% each).
Summative Examination (80%) (2 hours).

Feedback given to students in response to assessed work

Generic written feedback on examinations;
Individual feedback on request;
Model answers

Developmental feedback generated through teaching activities

Results of in-class tests and quizzes;
Results of Computer Aided Assessment;
Dialogue between students and staff in tutorials

Reading List

APPENDIX G: EVS QUESTIONS USED DURING INTERVIEW

363

For $\phi(x,y,z)=x^2 y^2+3xyz$, $\nabla\phi$ at the point (2,-1,1) is

1. $7\underline{i}-2\underline{j}+6\underline{k}$

2. $4\underline{i}+6\underline{j}-6\underline{k}$

3. $4\underline{i}+6\underline{j}$

✓ 4. $\underline{i}-2\underline{j}-6\underline{k}$

5. None of the above

6. Don't know

Loughborough University

9
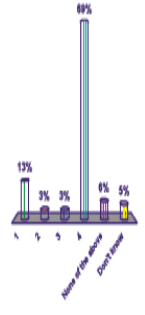
L18 The divergence of $\underline{F}=x\underline{i}-2y\underline{j}+xyz\underline{k}$ is

1. $(1+yz)\underline{i}+(xz-2)\underline{j}+xy\underline{k}$

2. $xy-1$ ☺

3. $\underline{i}-2\underline{j}+xy\underline{k}$

4. $-1+yz+xz+xy$

5. Don't know

n=47

Loughborough University

10
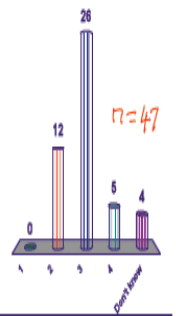
L19 Which of the following statements are true for vector fields $\underline{v}$ and scalar fields f?

☺ 1. div (grad f) exists and is a scalar

2. grad $\underline{v}$ exists and is a vector

☺ 3. grad f exists and is a vector

☺ 4. grad (div $\underline{v}$) exists and is a vector.

29%   28% 29%
14%

Loughborough University

11
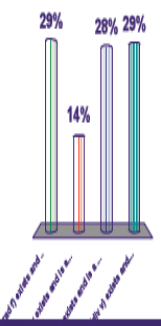
L19 Which of the following statements are true for vector fields $\underline{v}$ and scalar fields f?

1. curl (grad f) exists and is a scalar

2. curl (div $\underline{v}$) exists and is a vector

☺ 3. div (curl $\underline{v}$) exists and is a scalar

4. grad (curl $\underline{v}$) exists and is a vector.

46%
17% 20%   17%

Loughborough University

12
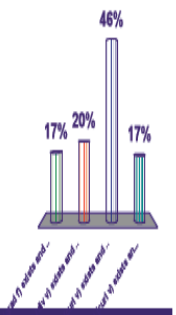
L19 — Find the value of a to ensure the flow is incompressible for $\underline{v} = axy\underline{i} - \frac{1}{2}y^2\underline{j} - yz\underline{k}$

1. 0
2. 1
3. 2
4. 3
5. Don't know

n=72
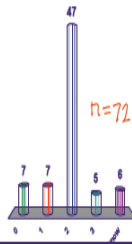
L6 — The integral represents what property of the region of integration? $\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} d\theta \int_0^1 dr \int_0^{r\cos\theta} r\,dz$

1. Mass
2. Volume ✓
3. Radius
4. Moment of inertia
5. None of the above
6. Don't know

n=62
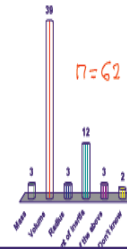
L7 — The determinant of $\begin{pmatrix} 2 & -3 & -1 \\ -4 & 5 & 1 \\ 1 & -2 & 3 \end{pmatrix}$ is

1. 70
2. -8
3. -16
4. 62
5. None of the above
6. Don't know

n=82
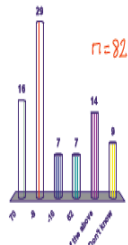
L7 — The system $\begin{array}{l} x_1 - x_2 = 5 \\ -3x_1 + 3x_2 = 1 \end{array}$ has

1. A unique solution
2. No solution
3. Infinitely many solutions
4. Don't know

n=98
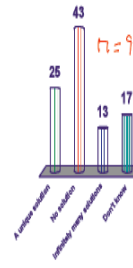
L9 — The inverse of $\begin{pmatrix} 1 & 1 \\ -3 & 1 \end{pmatrix}$ is

1. $\frac{1}{2}\begin{pmatrix} 1 & 1 \\ -3 & 1 \end{pmatrix}$
2. $\frac{1}{4}\begin{pmatrix} 1 & 1 \\ -3 & 1 \end{pmatrix}$
3. $\frac{1}{2}\begin{pmatrix} 1 & -1 \\ 3 & 1 \end{pmatrix}$
4. $\frac{1}{4}\begin{pmatrix} 1 & 1 \\ -3 & 1 \end{pmatrix}$
5. None of the above
6. Don't know
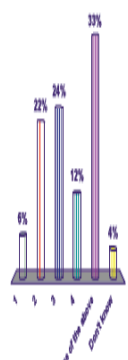
L17

The contours of f(x,y)= x-2y are

1. Straight lines of gradient -2
2. Straight lines of gradient +2
3. Straight lines of gradient ½ ✓
4. Straight lines of gradient -½
5. None of the above
6. Don't know
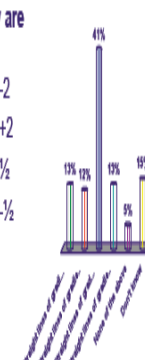
APPENDIX H: STAFF FOCUS GROUP QUESTIONS

Reasons for session

- To investigate student learning approaches to Algebra

- To investigate the effect of voting systems on learning mathematics

---

- Make S the subject of the formula

$$\frac{1}{S} = \frac{1}{S_2} + \frac{1}{S_3}$$

Make R the subject of the formula $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$

$$\frac{1}{R} = \frac{R_2 + R_1}{R_1 R_2}$$

1. $R = R_1 + R_2$
2. $R = (R_1 + R_2)/R_1 R_2$
3. ✓ $R = (R_1 R_2)(R_1 + R_2)$
4. None of the above
5. Don't know

(45%, 30%, 15%, 5%, 5%)

- Simplify the expression

$$5/x/y$$

$$1/a/b = \left(\frac{1}{a}\right)/b = \frac{1}{a} \times \frac{1}{b} = \frac{1}{ab}$$

$$1/(a/b) = 1 \times \left(\frac{b}{a}\right) = \frac{b}{a}$$

1. b/a
2. a/b
3. ab
4. $\frac{1}{(a+b)}$
5. None of the above
6. Don't know

(48%, 10%, 3%, 21%, 10%, 7%)

- Derive the reciprocal of:

$$\frac{x}{2} + \frac{y}{2}$$

The reciprocal of $\frac{a}{3} + \frac{b}{3}$ is

$$= \frac{(a+b)}{3}$$

1. $\frac{3}{a} + \frac{3}{b}$
2. $\frac{3}{(a+b)}$ ✓
3. $\frac{1}{3}(a+b)$
4. None of the above
5. Don't know

Reciprocal is $\frac{3}{(a+b)}$

(50%, 32%, 14%, 0%, 4%)

$$2 - (-5)^2 \div \frac{(-5)}{2} + 11 =$$

23	6
3	3
1	1
15.5	1
OTHER	5

Matching Keywords: 0
Keywords: NA

Bodmas $2 - (-5)^2 \div \frac{(-5)}{2} + 11 =$

$2 - 2\overset{5}{\cancel{5}} \times \frac{2}{(-5)} + 11 = 2 - (-10) + 11$

$= 2 + 10 + 11$

$= 23$

23	6
3	3
1	1
15.5	1
OTHER	5

Matching Keywords: 0
Keywords: NA

Which line best ... $y = -3x - 3$?

Which of the following would produce a straight line graph?

1. $5x + 3y = 3$ ✓
2. $-2x = -3 - \frac{5}{3}y$
3. $y = \sqrt{x} + 6$ ✗
4. $y = -\frac{2}{3}x^2$ ✗
5. $y = \frac{6}{x} + 10$ ✗
6. $y = -6$ ✓

A line has ___ . If x increases by 6, how much will y increase by?

1.5	10
6/4	5
24	3
0	1
OTHER	3

Matching Keywords: 0
Keywords: NA

Revision- Which of the following represent the sum 3+5+7+9+11+13?

1. $\sum_{n=1}^{6}(2n+1)$
2. $\sum_{n=0}^{5}(2n+3)$
3. $\sum_{n=2}^{7}(2n+5)$
4. $\sum_{k=2}^{7}(2k-1)$
5. Don't know
6. None of the above

The point $(0,2)$ lies on a line with gradient -3. The equation of the line is:

1) $y = -2x - 3$
2) $y = -2x + 3$
3) $y = -3x + 2$
4) $y = -3x - 2$
5) Not enough information
6) Don't know

Two points $(0,2)$ and $(1,3)$ lie on a straight line. Calculate the y-intercept of the line.

2	17
0	2
1	1
222222222	1
OTHER	3

Matching Keywords: 0
Keywords: NA

Which of the following are polynomials

1. $3x^2 + 4x + 2$ ✓
2. $\frac{1}{(x+1)}$ ✗
3. $\sqrt{x}$ ✗
4. $-x^2 + \frac{2}{x} + 3$ ✗

Which of the following equations are quadratic equations?

1. $6x^2 = 0$ ✓

2. $x^2 - 3x + 4 = 0$ ✓

3. $2x^2 - 3 = 0$ ✓

4. $3x + 4 = 0$ ✗

5. $1 + x - \frac{1}{x} = 0$ ✗

$x + x^2 - 1 = 0$ ✓

35%   100%   40%   10%   35%
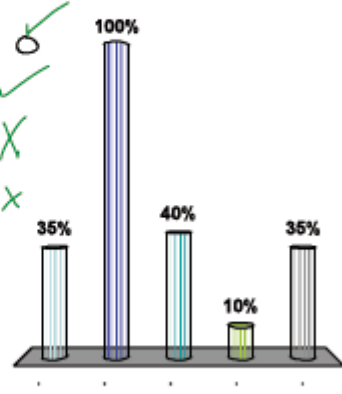
APPENDIX I: STUDENT FOCUS GROUP QUESTIONS

Slide 1

The *process* of counting leads to the *concept* of number. By various further strategies of process, "counting all" of two sets …or "counting on"… leads from the process of counting to the concept of "sum". (David Tall, 1991; p.253)

Mathematics is a highly regular subject, so learning maths requires…about 95% intelligent learning, 5% habit learning. (Skemp, 1971; p.35)

Slide 2 — Reasons for session

- Panel recommendation for mathematical thinking
- Research question: surface vs. deep learning
- Use of questions with voting systems

Slide 3 — Q1.

- Simplify

$$x^2 - (-5)^2 \div \frac{-5}{2} + 11$$

Slide 4 — Q.2 Sequences

5, 8, 11, 14, . . .

- Find the 6th term
- Find the 233rd term

Slide 5

$$X_n = 3_n + 2$$

$$a_n = a_0 + (n-1)d$$

Slide 6 — Q3. Series

- Use sigma notation to find the sum of the first 6 terms of the sequence:

3, 5, 7, 9…

Slide 7 — Series

$$\sum_{n=1}^{6} (2n+1)$$

Slide 8 — Q4.

- Which of the following would produce a straight line graph?

1. $5x + 3y = 3$ 2. $-2x = -3 - \frac{5}{4}y$

3. $y = \sqrt{5x} + 6$ 4. $y = \frac{2}{3}x^2$

5. $y = \frac{6}{5x} + 10$ 6. $y = -6$

369

Q5a.

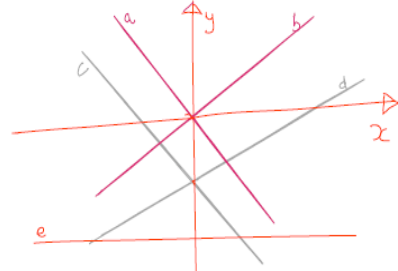- Sketch the graph of the function:

$$y = -3x - 3$$

Q5b. Which line represents $y = -3x - 3$

Q6.

- A point on a straight line has the coordinates (0, -2), and the slope of the line = -3. Find the equation of the line.

Q7.

- The coordinates for two points on a straight line are (0, 2) and (2,3). Calculate the y-intercept of the line. What is the distance between the two lines?

Q8a.

- For each of the linear equations given below, how would the gradient values affect the slope of the resultant lines?

1. $y = \frac{2}{3}x + 2$
2. $y = \frac{1}{4}x + 2$
3. $y = -x + 2$

Q8b.

- A line has gradient ¼. If x increases by 6 units, by how many units will y increase or decrease? What if the gradient of the line is 2/3 or -1?

1. $y = \frac{2}{3}x + 2$
2. $y = \frac{1}{4}x + 2$
3. $y = -x + 2$

APPENDIX J: REPORT ON FLIP VIDEO

+++**FLIP VIDEO CAMCORDER**
PROS
• Simple (and limited number of) controls – Easy to operate   • Easy to transfer files   • Durable/Relatively resistant to abrasion   • Portable   • Crisp picture quality   • Good audio capture   • Relatively non-intrusive   • Zoom function works ok   • Delete function works ok
CONS
• Play button not intuitive (playback button looks more like the play button)   • Can hold only 60 minutes of video   • Battery life (better to replace batteries after two hours of recording, to be on the safe side – as no indication of battery life is provided)   • Have to remember to transfer and delete files after each recording   • File size: a 60-minute recording would be more than 1G in size
RECOMMENDATIONS
• Have to practice how best to position camera for efficient capture/recording – the camera must be placed at a suitable angle/elevation relative to the target   • All users have to download XviD Codec (http://www.xvidmovies.com/codec/) and MAC users particularly have to follow the instructions on the site, http://www.xvidmovies.com/mac/ to be able to watch *and* listen to recordings.
FEATURES NOT USED
• Stand   • Watching on TV
+++ This document is based on the use of the Flip Video Camcorder for interviewing students on the MAB104 module in January 2009.

Table X Report on the use of Flip Video camcorder for video recording interviews with students.