How and why lecturers of mathematics at universities in the Kingdom of Saudi Arabia use or do not use ICT for teaching, a mixed methods study

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Abstract

This thesis has sought to examine how and why mathematics lecturers in Saudi Arabian universities use software for teaching. It is a large-scale, mixed methods study within a post positivist tradition, utilising data collected from interviews and a questionnaire. Eighteen lecturers from two mathematics departments at two major universities in the Kingdom of Saudi Arabia (KSA) were interviewed individually in their offices. Further, 151 lecturers responded to the questionnaire distributed to lecturers of Mathematics and Statistics at eight long-established state universities in KSA. This study explains why lecturers of mathematics at universities use or do not use ICT for teaching and, in so doing, contributes to an under-researched area of study. It raises questions as to how users and non-users of software regard the nature of teaching and learning of mathematics at universities and the contribution of ICT in university-level mathematics.

Previous research on the use of software by mathematics teachers has identified a range of factors affecting take up and use of ICT, including access to ICT resources, knowledge of how to integrate technology into mathematics teaching, and beliefs about the role of technology in learning and teaching and assessing mathematics (e.g. an overreliance on technology, use of technology as a black box, use of calculators in examinations). However, there remains ongoing debate about the balance of internal and external factors in the take up of ICT and whether factors related to easy access to software are more (or less) influential than teachers' beliefs.

The findings of this study revealed that identification with the branch of mathematics was a key factor in determining the lecturers who are likely to be users of software in teaching. In particular, it was found that statisticians and computational mathematicians were more likely to be users of software because they were teaching courses which require the use of software. The findings suggested that despite all of

the encouraging conditions, contextual and internal barriers— such as a curriculum with heavy and fixed content; software which was not assessed in many cases; lack of cooperation between lecturers to produce curricula which included the use of software; and doubts about the value of software—were at work here.

This study has a special interest in Valsiner's Zone Theory as a lens to study the take up of ICT. In particular, the Zone Theory demystifies why the take up of mathematical software by the mathematics lecturers was patchy despite the good access to ICT resources and the high potential of the use of software in mathematics teaching. From the Zone Theory's perspective, lecturers worked within a particularly broad zone of free movement but a weak zone of promoted action so that lecturers' activity was rarely 'canalised' into using mathematical software. The Zone Theory puts emphasis on agency-structure dualism, focusing on the actions carried out by individual lecturers as 'agents' in the context of constraining and enabling 'structures' when making a decision on whether software should be used in teaching. This thesis has reaffirmed the call for more theoretical and empirical research on the issue of the integration of mathematical software in the teaching and learning of mathematics in higher education.

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Chapter 1 Introduction

1.1 Introduction

This thesis explores how lecturers of mathematics at universities use software in teaching and for what reasons. It is a mixed methods study utilizing data collected from interviews and questionnaire. It explains why mathematics lecturers at universities in the Kingdom of Saudi Arabia (KSA) use or do not use ICT for teaching, contributing to an under-researched area of study. It raises questions as to how users and non-users of software regard the nature of teaching and learning mathematics at universities and the contribution of ICT in university-level mathematics.

Mathematicians and mathematics educators alike have noted the difficulties faced by many students in trying to understand mathematical concepts. They have observed obvious weaknesses in students' basic mathematics skills. From the initial stages of the calculus, for example, some students find the basic idea of limit, continuity and differentiation difficult. Most mathematical courses present definitions, axioms, theories and other mathematical ideas in an abstract and formal way. Students, by nature, tend to feel more comfortable with concrete ideas. The use of mathematical software such as Computer Algebra Systems (CAS) has the potential to facilitate students' understanding of complex mathematical ideas. Software provides speed and automated features that enable users to carry out technical calculations quickly, and it allows teachers and students to visualize complex three-dimensional shapes that would be impossible in the absence of the software. Mathematical software provides more time to focus more on ideas, rather than procedural calculations.

In spite of the benefits that mathematical software provides, it is perhaps surprising to see that use is 'patchy.' Indeed, many authors (e.g. Drijvers and Herwaarden 2001; Bretscher 2008; Lavicza 2010) have identified a general pattern - one which begins with high hopes and ends up with a disappointment concerning the limited use of technological tools in mathematics. This suggests that integrating mathematical software in education is a complex process, requiring further theoretical and empirical research.

Previous research on the use of software by mathematic teachers has identified a range of factors affecting the use of ICT. These include: access to hardware and software; technical support, skill and experience in using technology (pre-service education, professional developments), availability of appropriate teaching materials, institutional culture, knowledge of how to integrate technology into mathematics teaching (instrumental genesis), beliefs about the role of technology in learning and teaching and assessing mathematics (e.g. an overreliance on technology, use of technology as a black box, use of calculators in examinations) and beliefs about mathematics and how it is learned (e.g. Beswick 2005; Ertmer 2005; Laborde 2007; Goos and Bennison 2008; Buteau *et al*. 2010; Lavicza 2010; Stols and Kriek 2011). However, there remains ongoing debate about the balance of internal and external factors in the take up of ICT and whether factors related to easy access to software are more (or less) influential than teachers' beliefs. Few researchers study this area in the context of the Kingdom of Saudi Arabia, where this research took place.

Contemporary research takes place in a changing context. There is easier access to information on the Internet at home and in schools, colleges and universities. We are witnessing the availability of a wide range of mathematical software packages that cover many of the key topics of the various mathematical courses at the university level. This big change in availability and accessibility naturally raises questions about the impacts of such technological tools on the teaching, learning and assessment of mathematics. This research is an attempt to explore the adoption of software by mathematical lecturers during their teaching of undergraduate mathematics courses, as well as the factors that encourage or discourage the use of such software when teaching undergraduate mathematics courses. I chose mathematical lecturers to be the target of this research because a decision on whether and how to use information and communication technology (ICT) for instructional purposes lies ultimately on their shoulders.

In Saudi Arabian universities, the conditions for successful technology integration appear to be in place, including easier access to ICT, training for lecturers to use ICT tools and favourable governmental policy towards more integration of technology in education (Ministry of Higher Education 2013). Despite all of these encouraging conditions, evidence suggests that technology use in teaching has been low (Alkhurbush 2011). This may suggest that additional internal (cognitive, emotional, or cultural) barriers—such as lecturers' resistance to change and their pedagogical beliefs—might be at work here.

Mathematicians have different views about their subject and this has been used to offer an explanation as to the embracement of ICT. Some might describe mathematics in terms of formulas, procedures and specific skills. Others may see mathematics as a way of thinking—focusing on the concepts and big ideas more than calculations and mastery of skills. Some mathematicians might see their subject as a static body of knowledge, whereas others view mathematics as a dynamic and continually growing knowledgebase (Ernest 1989). It is perhaps relevant to study the association between lecturers' views about the nature of mathematics and their practice of teaching the subject—especially in relation to their views of the affordances of ICT. This is because, as Skemp (1976) argued, teachers' conceptions of mathematics have an impact on the way that they teach the subject.

The social and cultural environment on the individual's decision to use the technology might be overlooked when discussing factors influencing the use of technology in teaching. This explains the attraction of Vygotsky's work—and later Activity Theory—in describing and understanding human activities as mediated by tools and bounded by social rules. We can apply that to the context of individual users interacting with technology. My thesis uses Valsiner's (1997) three zones theory as an explanatory framework to study the interactions between lecturers, students, technology and the surrounding teaching-learning environment. My research puts emphasis on the agency-structure dualism—focusing on the actions carried out by individual lecturers as 'agents' in the context of constraining and enabling 'structures' when making a decision on whether software should be used in teaching.

1.2 Technological Tools Covered By This Research

The research looks at mathematical software capable of performing tasks in one of the following ways:

(a) By manipulating algebraic objects, expressions, equations and symbols (such as in Algebra or Calculus) using commands and built-in functions. Computer algebra systems (CAS) include almost all mathematical software packages that are used in most university courses nowadays. Maple and Mathematica are two widely used comprehensive CAS.

(b) By running numerical computations and implementing algorithms when symbolic solutions are not possible (such as in Numerical Analysis and Computation Mathematics). Matlab is the most widely used software in computational mathematics and is used in engineering courses.

(c) By running statistical analysis of data (such as in multivariate analysis, analysis of variance and regression analysis). SAS, Minitab, SPSS and Statistica are all examples of software that are used within statistical courses.

(d) By producing two and three dimensional plots of curves and surfaces such visualizing the solutions of ordinary or partial differential equations, or by producing and manipulating geometric constructions. All mathematical software has plotting functionality. Cabri Geometry and the Geometer's Sketchpad are popular Dynamic Geometry Software (DGSs) for exploring Euclidean geometry. GeoGebra is a free DGS, with CAS capabilities.

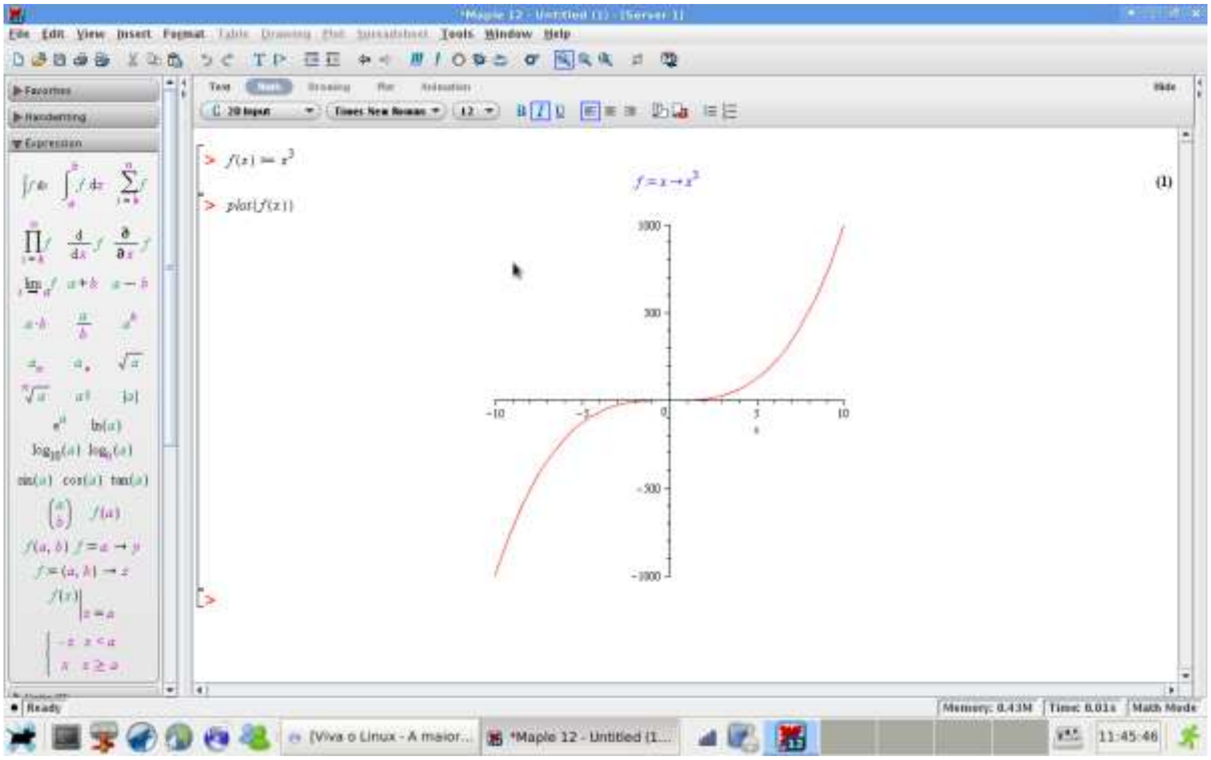
I will now describe these in more detail.

Computer Algebra Systems (CAS)

Derive is an example of a CAS which can perform symbolic, numeric and graphical operations. Derive, a menu-driven program, allows users to select options by positioning the highlight over the appropriate name and then pressing the Enter key. Three types of Windows or screens exist in Derive: There is the Algebra Window, in which the user performs either symbolic or numeric operations. Secondly, there is the 2D Plot Window for displaying two dimensional graphs. And, finally, a 3D Plot Window can plot three dimensionally (**{** HYPERLINK "http://faculty.madisoncollege.edu/alehnen/mpptutor/comf00.htm" **}**).

Maple is a general-purpose commercial CAS used by engineers, mathematicians and others. It possesses many features including 'Math Equation Editor,' which allows the user to express mathematical problems using standard mathematical notation. 'Visualization' enables the users to create two and three dimensional plots with animations features. In Maple, there is a category under Mathematics featuring a range of sub-options, including the following: 'Symbolic and Numeric Math,' in which one can perform numeric computations and symbolic manipulation; 'Comprehensive Mathematics,' which offers coverage of a vast range of mathematical topics; and 'Equation Solving,' which offers symbolic and numeric methods and algorithms to solve equations (Linuxlinks.com 2009).

Figure 1: plotting a function in MAPLE (Source: Linuxlinks.com 2009)

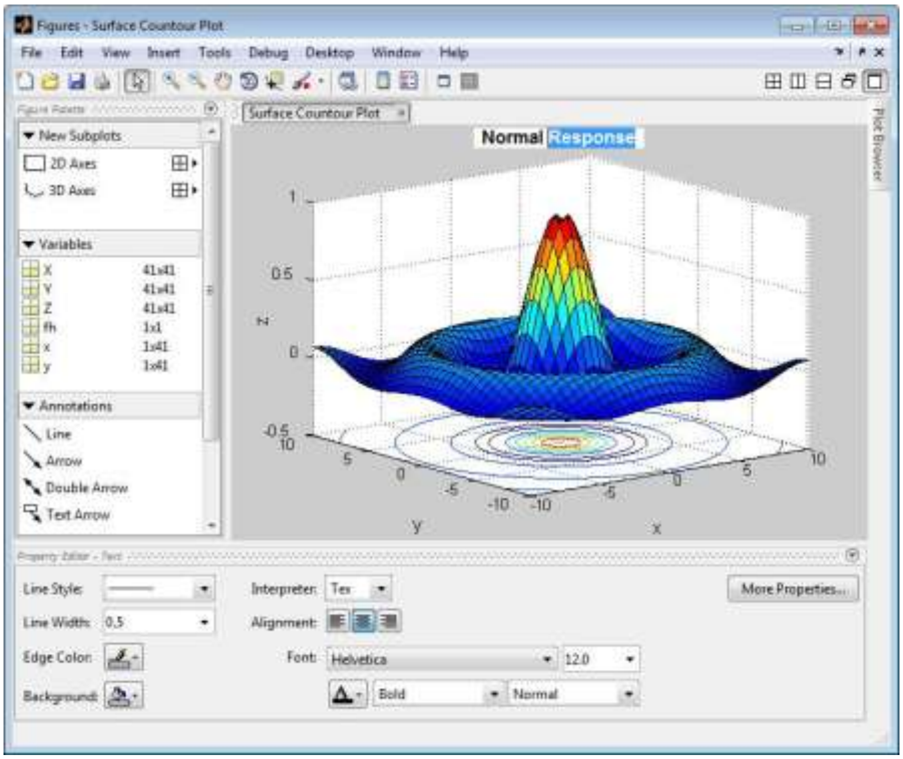


Numerical Analysis Packages

Numerical Analysis is the study of algorithms that use numerical approximation (as opposed to symbolic manipulations as in Calculus and Algebra). Many CAS packages can also be used for numerical computations. There are various collections of software routines for numerical problems, mostly written in traditional languages such as FORTRAN and C++.

MATLAB is a popular numerical analysis package with CAS capabilities. It offers an interactive environment for numerical computation, visualization and programming. It has rich, built-in mathematical functions that enable users to write programs and implement algorithms faster than with any traditional programming languages. MATLAB language takes care of low-level administrative tasks such as declaring variables, specifying data types and allocating memory. The support of matrix operations eliminates the need for doing loops (MathWorks.com). Figure 2 shows an example of plotting the function of two variables (z=f(x, y) =sin(R)/R; R=x^2+y^2) using built-in 3-D plotting functions in MATLAB.

Figure 2: Plotting a function of three dimensions in MATLAB (Source: MathWork.com 2013)



Statistical Packages

Statistical software packages are specialized computer programs for statistical analysis. SAS and STATISTICA are two comprehensive statistical analysis packages. They enable programmers to perform all sorts of data analysis such as analysis of variance, regressions analysis, categorical data analysis and multivariate analysis. Minitab is another popular statistical analysis package. SPSS is a software package used widely in social sciences for statistical analyses. The most recent version of SPSS was IBM SPSS Statistics 22.0 – released in August 2013.

Various classifications of educational software apply to mathematical software used at universities. Kemmis's *et al*. (1977) classified the use of computers in education into four paradigms labeled as instructional, revelatory, conjectural and emancipatory paradigms (Table 1). This influential model was based on the educational role intended by the use of software (McDougal *et al*. 1977; Collins, Hammond, and Wellington 1997).

Table 1: Kemmis's et al., Paradigms for computer assisted-learning (McDougal et al. 1977; Collins, Hammond, and Wellington 1997)

The Instructional Paradigm	-based on behaviorist theory -the software functions as a tutor - programmed learning - drill-and-practice or tutorial software (courseware)
The Revelatory Paradigm	-based on Bruner's spiral curriculum -contents are progressively revealed to learners through a process of step by step enquiry -learning by discovery or experiential learning, simulation.
The Conjectural Paradigm	-based on constructivist theories -learner has control, create models, produce and implement his/her own codes -computer as a tool: word processor, modeling, programming.
The Emancipatory paradigm	-computer as a labor saving tool -may occur in conjunction with one of the other three -removes the need for laborious and repetitive tasks that are not relevant to the learning objective but are necessary to be carried out

This kind of categorization focuses on what the software does, rather than what the user does with the software. The packages described earlier can be used within both behaviorist and constructivist instructional strategies. They can fall under one or more of the four paradigms mentioned above. All of these packages exemplify emancipatory software as they reduce the workload of teacher and students, saving them from tedious, time consuming and routine calculations. They do not—in themselves—contain learning material; they are content free. They can be conjectural, since they have programing capabilities and can be used in modelling a real-world system. Courseware or 'instructional software' based on these programs is available. MAPLE T.A. is a Drill and Practice web-based software designed for any course that required mathematics ({ HYPERLINK "http://www.maplesoft.com/products/mapleta/" }). These are examples of revelatory software. One can explore a particular system by simulating a mathematical model of that system. Arena, Lingo and Lindo are examples of simulation software that are frequently used in operations research and optimization courses in mathematics departments.

In addition to mathematical software, this research touches on lecturers' use of general purpose software such as PowerPoint presentation, smart board and virtual learning environments (VLEs). I decided to include these general purpose applications for two main reasons: first, it would serve as an indicator to lecturers' overall use of ICT and to their skills and readiness towards working with ICT tools, and, secondly, to examine whether there is an association between the general uses of software with specific uses of mathematical software in teaching.

VLEs, also known as Learning Management Systems (LMS), are web-based systems for delivering learning materials to students. They include student tracking, assessment and communication tools. Instructors can use VLEs to upload lecture notes and course materials, track and assess students' progress, as well as to communicate with students. The most commonly used VLEs are Blackboard, WebCT (acquired by Blackboard in 2006), Moodle or universities' own systems. E-learning, a category of which VLEs belong, refers to learning via electronic means, typically the Internet (TechTerms.com 2013).

From students' perspectives, VLEs allow them to self-enrol, access course resources whenever and wherever they are online, facilitate submission of assignments, receive instructors' feedback and enable them to communicate through email and discussion boards with students and instructors (King Saud bin Abdul-Aziz University for Health Sciences 2013).

VLEs can support collaborative learning by enabling users to interact with each other, organize discussion, and post and reply to messages. The communication tools in a VLE include synchronous (e.g.

live chat, video conferencing) and asynchronous (e.g. electronic mail, forums) communication (Laurillard 2002). As asserted by Dillenbourg (2000), an obvious opportunity of VLEs is that—in addition to an unlimited accessibility to information—they would potentially increase the opportunity of collaborative learning. But in the end, what matters is the pedagogical effectiveness and functionality of any educational tool (ibid).While some may believe that a VLE cannot fully replace the traditional face-to-face teaching method, the two methods of instruction can be combined together, creating what is known as 'blended learning'.

Having provided a background to mathematical software, I now move on to the so-called 'how and why' of my research.

1.3 An Overview of the Research Methodology

I sought to examine how and why mathematics lecturers in Saudi universities use software for teaching. I employed a mixed methods study, comprising semi-structured interviews and survey questionnaire. The semi-structured interviews aimed primarily to explore the views of mathematics lecturers on how and why they use software in teaching undergraduate mathematics and statistics. The survey was a means to reach the largest possible number of lecturers in the country and to extract further evidence on how and why lecturers of mathematics and statistics from different universities in KSA use or do not use ICT for teaching—and particularly on the factors that may encourage or discourage lecturers from teaching mathematical courses using software.

Using the terminology of Teddlie and Tashakkori (2006), the overall design of this research can be described as a Concurrent Mixed Methods Two-Strand Design. This means that the research involved two relatively independent phases (two strands): quantitative and qualitative. These two phases yielded two forms of data, qualitative and quantitative. I collected data and then analysed it independently and separately. Integration occurred at the data interpretation stage.

The participants of the study were lecturers of mathematics in long established departments of mathematics in Saudi Arabian government universities. These universities, spread over different parts of the kingdom, are under the direct supervision of and receive support from the government represented by the Ministry of Higher Education. I used interviews and questionnaire to collect data from mathematics and statistics lecturers. I interviewed 18 lecturers from pure, applied, computational and statistics branches of mathematics. I subsequently administered a questionnaire to lecturers in mathematics and statistics at eight universities. Most respondents (three-quarters of the total responses) delivered hard copies and about one-quarter used email.

For the interview phase of the research, two mathematics departments were selected at two major universities in the Kingdom. I chose these departments purposively. I speculated that the first university—from which I graduated—was likely to be a 'low user' of ICT in the undergraduate mathematics courses in general and in mathematical software in particular. On the other hand, it was well known that the second university, which was more specialized in the field of science and engineering, leads the country in the use of technology (see Chapter 3).

At each university visit, I conducted in-depth interviews with lecturers from different branches of mathematics departments (i.e. pure, applied, computational and statistics). I consulted the heads of departments of mathematics first to determine a group of faculty members from different branches of mathematics who were more likely to want to talk about software in teaching. This biased the sample towards those who were inclined to use ICT. However, I gathered a breadth of opinions through the interviews. Some interviewees turned out to be non-users of ICT. The sample was not, then, strictly representative of the population. However, I accessed pure, applied, computational mathematics and statistics lecturers, and I gained an insight into them. All interviewees were male, though some taught in the female faculty. I interviewed them individually after arranging appointments during working hours. I prepared an interview schedule containing four main themes: use of software (the 'what', 'how', and 'where' questions, etc.), the value of software use (the 'why'), barriers to software use (the' why not') and the issue of overreliance on technology—which proved to be a major hindrance to software use, stemming from the literature (e.g. Buteau *et al.* 2010). I transcribed the interviews. I grouped the coding and comments (using the software NVivo).

In the second phase, I administered a questionnaire to a total of 421 faculty members from the departments of mathematics and statistics at eight state universities in the Kingdom of Saudi Arabia. At the time of the research, these eight universities were well established and the logic of their inclusion was straightforward. However, since carrying out the research, departments of mathematics and statistics in new universities have emerged. These were not included in the project, as they were in the process of establishment and access was difficult (e.g. web pages for these departments at that time did not exist).

I delivered the questionnaire in hard-copy format (printed versions) to a total of 170 faculty members and through the Internet via e-mails to a further total of 251 faculty members. The items in the questionnaire explored how lecturers with research interests in Pure, Applied, Computational and Statistics used software packages in their teaching and their rationale for ICT use. Some items explore the association of variables such as teaching experience, areas of research, nature of course, nature of students and access to ICT facilities with use of software packages. Some questions in the questionnaire were about the rationale for use and other questions were about the use of virtual learning environments (VLEs). One hundred and fifty-one lecturers responded to the questionnaire, either through hard copies (109 lecturers) or via an electronic version (42 lecturers). I analysed the questionnaire data using SPSS software.

Although the survey covered both male and female faculties, one obstacle I faced—especially when conducting the interviews phase of the study—was the inability to access the female universities due to the policy of gender segregation in education.

1.4 Research Objectives and Research Questions

This research concerned the role of Information and Communication Technology (ICT) and mathematical software—in particular, at the university level in Saudi Arabia. My study attempted to answer the following questions:

RQ1. How, and to what extent, do lecturers use the software in the teaching of university-level mathematics courses?

RQ2. What is the context in which lecturers use ICT in the teaching of university-level mathematics?

RQ3. Do particular individuals or groups of mathematics lecturers use software more than others?

RQ4. What encourages/motivates lecturers to use the software in the teaching of university-level mathematics courses?

RQ5. What discourages/ constrains lecturers from using the software in the teaching of university-level mathematics courses?

1.5 The Kingdom of Saudi Arabia

Before embarking on the rest of the thesis, I will discuss the background to the Kingdom of Saudi Arabia (KSA) and the challenges facing higher education in KSA.

KSA is an Arabic and Islamic country situated in in the south-west corner of Asia. KSA—which is the home of the two holiest cities to Muslims, Makah and Medina—comprises about 80% of the Arabian Peninsula, with a total area of around two and a quarter million square kilometers—or nearly one quarter of the area of Europe. KSA is bordered on the west by the Red Sea, on the south by Yemen and Oman, on the east by the Gulf, United Arab Emirates and Qatar—and on the north by Jordan, Kuwait and Iraq.

Riyadh—the capital of the country—is located in the heart of the central region. Jeddah in the western region on the coast of the Red Sea, Dammam in the Eastern Province on the Gulf Coast, Makah, and Medina are the main cities in the Kingdom. KSA has an economy largely based on the export of oil and related products (see the map of the KSA in Figure 3).

Figure 3: Map of the KSA (source: **{** HYPERLINK "http://www.lonelyplanet.com/maps/middle-east/saudi-arabia/" **}**)

According to the 2011 census, the population of Saudi Arabia was estimated at 28.4 million, including nearly 19.4 Saudis and about 9 million non-Saudis. Riyadh was the most populous city, and the Western Province was the most populous province in the Kingdom. The capital has a population of more than 5 million, and Jeddah and Makah were second and third with populations of nearly 3.5 million and 1.5 million respectively (Central Department of Statistics & Information 2012).

As of 2012, according to the ICT Indicators Report, prepared by the Communications and Information Technology Commission in KSA, 15.2 million internet users log on in Saudi Arabia (representing 52% of the population). The number of households with broadband connections in Saudi Arabia was estimated at around 2.25 million households by the third quarter of 2012 (increased from only about two hundred thousand in 2006, which is about 1,025% percentage increases). These figures point to the rapid increase in demand for broadband services by the general public compared with previous years.

Higher Education in KSA

The Kingdom started making five-year development plans in 1970. The main objective of these consecutive plans has been to monitor progress in relatively short periods and to be able to change direction if necessary, especially since the government revenues rely heavily on the level of production and the prices of oil (Ministry of Economy and Planning 2012).

According the Ministry of Economy and Planning (2013), development of human resources is one of the goals of the Ninth Development Plan (2010-2014). The human resources development sector includes: general education, higher education, technical and vocational training as well as science, technology and innovation. During the period of this plan, the Kingdom planned to spend about 731.5 billion Saudi Riyals (195 billion U.S. Dollars) in the human resources sectors, nearly half of the total allocation for all developmental sectors. The Kingdom's commitment to invest in human development sectors might be tied to demographic makeup. The estimates of the year 2012 indicated that 28.2% of the total population of the kingdom was less than 14 years old and 19.6% of the total population was between 15 and 24 years old (CIA World Fact Book 2013). A young population puts a strain on services and infrastructure available in the country, especially in education.

There are three main authorities in charge of education: the Ministry of Education, the General Establishment of Technical Education and Vocational Training, and the Ministry of Higher Education. In general education—managed by the Ministry of Education—there are six years of elementary (primary) levels, three years of intermediate and three years of secondary levels. General Establishment of Technical Education and Vocational Training are the principal providers of technical education represented in hundreds of technical colleges, vocational secondary schools and training centers (Al-Dossary 2008).

The Ministry of Higher education, established in 1975, supervises and manages universities. The state budget finances these universities. They are non-coeducational, which means females and males study in separate campuses at all colleges and universities. The five major universities in the Kingdom are King Saud University in Riyadh, King Abdul-Aziz University in Jeddah, King Faisal University in Al-Ahsa, Imam Muhammad bin Saud in Riyadh and Umm Al-Qura University in Makah. All are open to male and female students in separate campuses. Women attend all five major universities, as well as numerous female colleges and private, all-women universities.

According to the 2012 Academic Ranking of World Universities (ARWU), King Saud University (KSU) in Riyadh ranked among the top 300 universities around the world for the 2012 annual assessment of the world's top 500 universities. KSU, in addition to King Abdu Aziz University (KAU) and King Fahd University for Petroleum and Mineral (KFUPM), both placed among the top 400 universities. They were the only Saudi universities and top Arabic universities in the ranking. In Mathematics, ARWU gave

KFUPM the rank 50, KAU came between 51 and 75, and KSU was given a rank between 76 and 100 among top universities around the world (Shanghai Ranking Consultancy 2012).

As of the 2012 academic year, there were 23 government universities spread over all the 13 provinces of the kingdom. Table 2 shows a list of government universities, their locations, the date of their establishment and the total number of students and staff—according to 2012 statistics from the Ministry of Higher Education.

Table 2: Government universities in KSA (Ministry of Higher Education 2012)

No.	University	Year of inception	Location (City)	Total Enrolment	Total Staff
1	King Saud University	1957	Riyadh	66,020	6,997
2	Imam Muhammad bin Saud Islamic University	1974	Riyadh	88,158	3,372
3	Umm Al-Qura University	1949	Makah	67,742	3,372
4	Islamic University	1961	Medina	13,394	620
5	King Fahd University of Petroleum and Minerals	1963	Dhahran	10,965	885
6	King Abdul-Aziz University	1967	Jeddah	132,094	6,148
7	King Faisal University	1975	Al-Ahsa	60,228	1,052
8	King Khalid University	1999	Abha	49,353	2,402
9	Taibah University	2003	Medina	53,234	1,917
10	Taif University	2003	Taif	42,158	1,726
11	Qassim University	2004	Buraydah	52,166	3,175
12	University of Hail	2005	Hail	28,096	1,458
13	Jazan University	2006	Jazan	33,862	1,578
14	Al Jouf University	2005	Al Jouf	19,334	947
15	Al Baha University	2006	Al Baha	18,411	707
16	University of Tabuk	2006	Tabouk	22,040	1,044
17	Najran University	2006	Najran	16,535	931
18	Northern Borders University	2007	Arar	8,386	587
19	University of Dammam	2009	Dammam	32,895	1,802
20	Salman Bin Abdulaziz University	2007	Al-Kharj	22,997	1,150
21	Shagra University	2010	Shagra	19,382	1,240
22	Almajmaah University	2010	Almajmaah	12,195	506
23	King Saud bin Abdul-Aziz University for Health Sciences	2005	Riyadh	723	1,618
	Total			898,251	45,593

The data in Table 2 shows 14 newly founded universities (founded on or after 2003). These universities are geographically distributed in different provinces of the Kingdom. From the statistics in Table 2, high student to staff ratios in most of the government universities in KSA (the overall student/staff ratio was 1:19.7) impose considerable burdens on university lecturers.

With regard to the criteria for admission to Saudi higher education institutions, before the year 2000, the sole criterion for both male and female students was the total score in the final secondary school examination. King Fahd University of Petroleum and Minerals (a male-only university) was the only exception utilizing its own entrance tests.

Since 2000, all students wishing to enrol in any higher educational institutions must sit a national standardized test administered by the 'National Center for Assessment in Higher Education'. This test, which is called the General Aptitude Test (GAT), aims to measure a student's potential abilities in academic skills in fields such as English language, Mathematics, Sciences and deductive skills. In all higher educational institutions, selection of newly admitted students should be decided on the basis of a combined score of both the secondary school cumulative score and GAT's cores. Every college and university, however, has its own method of interpreting the weight of each of GAT and the secondary school score (National Center for Assessment in Higher Education 2013).

In an attempt to ease the transition between formal education and higher education and to prepare secondary school graduates to university studies, all universities in the Kingdom require applicants to pass a preparatory year in order to be fully admitted to their undergraduate programs. The Preparatory Year is an intensive program focusing on improving students' skills in English, Mathematic, ICT and other basic skills necessary for future studies at universities (Ministry of Higher Education 2013; King Saud University 2013).

Regarding the number of students and faculty members—male and female—in Saudi universities, the statistics of the Ministry of Higher Education (see Table 3) show that the number of female students outnumbered their male counterparts in most well-established universities such as King Abdul Aziz University, Umm Al Qura University, King Faisal University and King Khalid University. The total male faculty members exceeded the number of their female counterparts in all the well-established universities. These figures show that the opportunities for male students were better than their female counterparts in most of Saudi universities. This may explain why some of the courses offered to female students are taught by men through the CCTV system to overcome the problem of an insufficient number of female faculty members available to girls.

Table 3: Staff and students for universities in KSA (Ministry of Higher Education- 2011 statistics)

Educational Institution	Total (Staff)	Gender (Staff)	Total (Full-time) enrollment for Bachelor Degree (students)	Gender (students)
King Saud University (KSU)	6,997	2,357 F	55,623	25,194 F
		4,640 M		30,429 M
King Abdul Aziz University (KAU)	6,148	2,849 F	41,894	25,244 F
		3,299 M		16,650 M
King Fahd University of Petroleum and Minerals (KFUPM)	885	0 F	8,544	0 F
		885 M		8,544 M
Umm Al Qura University	3,372	1,274 F	52,963	29,894 F
		2,098 M		23,069 M
Islamic University	620	0 F	9,329	0 F
		620 M		9,329 M
Imam Muhammad Ibn Saud Islamic University	3,372	923 F	47,185	19,993 F
		2,449 M		27,192 M
King Faisal University (KFU)	1,052	381 F	19,745	12,050 F
		671 M		7,695 M
King Khalid University (KKU)	2,402	957 F	40,488	28,006 F
		1,445 M		12,482 M

Al-Dakhil (2011) and Alamri (2011) discussed a number of key challenges facing higher education in Saudi Arabia, which can be summarized as follows:

First, ensuring the quality of higher education outcomes requires control over the number of students enrolled in universities so that they remain within acceptable limits compared to the number of teachers and the available infrastructure, facilities and services. The steady increase in the number of secondary school graduates with no job opportunities, however, has led the government to 'pressure' the universities to accept large numbers of students. This imposes a heavy burden on the available resources at these universities as well as faculty members—who are already overloaded, which could have a negative impact on the teaching standard at these universities. Managerial issues abound too. Higher education tends to be over-regulated by government bureaucracy and various authors have argued for a change. The way the government supports universities, for one example, can be changed to an annual lump sum. This could be allotted under certain conditions, provided that the universities admit a limited number of students for free, quality university education in return for enjoying full autonomy.

Second, under government pressure, higher education ended up accommodating a lot of students—regardless of whether or not they prefer their allocated courses, and regardless of the immediate or future occupational possibilities. If people and the government both consider that the goal of higher education is to obtain a college degree in any field, regardless of specialty, this will create a huge increase in the numbers of graduates who hold university degrees but are unable to fit into labour market. This will steadily decrease the value of a university degree.

Third, Alamri (2011) reported that there is high percentage of non-Saudi faculty with no motivational system for them in terms of salaries and incentives, compared to Saudi faculty members. Saudi universities need to attract more non-Saudis faculty members, especially those who are distinguished in their fields and are active in the research. They may serve as a model for novice faculty members. Well-educated faculty members positively impact the colleges and universities. Their presence would attract other outstanding academics to join those universities. In order to attract such faculty members, it is necessary to provide them with lucrative salaries and other attractive benefits more than what they earn at other universities—especially those who come from the developed countries.

Technology in Saudi Arabian Higher Educational Institutions

According to 'National Report of the year 2009' by Ministry of Higher Education, the number of high school graduates in the country has increased many times during the past fourteen years. For example, in the period 1993-2008, the number of secondary school graduates increased by 443%. By the end of the Ninth Development Plan (2010-1014), the goal has been to expand the capacity of universities in the country to 1.7 million students (Ministry of Economy and Planning 2013). All of the above has enormous significance for the country's educators and policymakers. They ought to keep up with the flow of students entering universities year after year. In addition to that, the country has—as previously mentioned—a highly segregated culture, where there is a separation maintained between the male and female staff and students. This doubles the burden and adds a considerable strain on available resources and accommodation. VLEs, and other e-learning tools, thus have the potential to accommodate more students and to obtain a good quality education for both sexes (Asiri *et al*. 2012)

The Saudi government represented in Ministry of Higher Education seeks to deploy ICT systems in all higher educational institutions. This is reflected through the establishment of e-learning faculties in all of the Saudi universities (Alqahtani 2010). The ministry of higher education has established the National Centre of Electronic Learning and Distance Education (NCeL) to develop a range of activities aimed at spreading e-learning applications and solutions in all higher education institutions. NCeL manages a number of projects: JUSUR LMS System, SANEED and MAKNAZ.

JUSUR was built based on the LMS of the Open Malaysian University, with some new features and tools added to meet the needs of the universities in Saudi Arabia. JUSUR allows the student to access the courses, grades and assignments. Instructors and administrators can also access courses and reports (NCeL 2013). Table 4 shows the key features of JUSUR.

Table 4: The Key Features of the JUSUR System (NCeL, 2013)

Log in	Registering students in the portal
Schedule	Planning the course and the way of teaching it
Delivery	Making the course available for users
Tracking	Following up the students' progress as well as issuing reports of student performance
Communication	Students can contact each other through forums, emails and file sharing.
Evaluation	Testing students through quizzes and examinations and grading them

Other than JUSUR, the NCeL has launched other projects. The Saudi Center for support and counseling (SANEED) has been established to provide advisory support and guidance to all users of JUSUR, whether students or faculty members. SANEED provides solutions and services through multi-communication channels such as a call centre, live voice connection, email, chat, fax and SMS. Another project is the National Repository for Learning Objects, known as MAKNAZ—serving as a basis for building digital curricula for all universities' courses in the country. The NCeL, in addition, provides training to faculty members and technical staff in the Saudi universities (NCeL 2013).

Regarding JUSUR, a study was conducted by Zouhair (2010) to evaluate the students' and instructors' levels of satisfaction in utilizing JUSUR as an e-learning system in a particular course. The results suggested that JUSUR was a good e-learning system and that the participants in the study would likely use it in future courses.

Despite the opportunities which JUSUR provides, Hussein (2011) concluded that its adoption by teachers has been patchy in most Saudi universities. According to Hussein (ibid), most of the male and female members of the faculty using JUSUR across disciplines held positive attitudes towards it. Most users identified the absence of direct technical support during their use of JUSUR as a major obstacle when dealing with it, however. Most respondents stressed the need for more training courses in how to use the system to attract more faculty members and students to use this system. Maashi (2009) also pointed

NCeL cannot provide sufficient technical support to all of the universities using JUSUR. For instance, the King Saud University previously used JUSUR, but recently, it has shifted to Blackboard for the same reason. Table 5 demonstrates the Saudi universities which has been using VLEs and other e-learning systems.

Table 5: Some Saudi universities and their VLEs

University	VLEs
King Saud University	Blackboard, JUSUR
King Abdul-Aziz University	The E-Learning, Management Electronic System (EMES), The Virtual Class Room System (CENTRA), JUSUR
King Fahd University of Petroleum and Minerals	Blackboard CE, WebCT CE 8, Live Virtual Communication (Centra Live), JUSUR
King Faisal University	WebCT LMS, Blackboard 9.0, JUSUR
King Khalid University	Blackboard, JUSUR, Electronic Testing (Questionmark), Virtual Classroom (Elluminate)
Umm Al-Qura University	JUSUR
Taibah University	JUSUR
Jazan University	JUSUR
University of Dammam	Blackboard, JUSUR

I conclude this overview about the technology in Saudi universities by presenting the results recently implemented in four universities, located in different provinces of the KSA. The first study, conducted by Alkhurbush (2011), adapted a case study methodology by using a university in the Western Province as a case then generalizing the finding using secondary information from a variety of sources. Alkhurbush (ibid) found that, despite the Saudi government's investment of substantial amounts in developing ICT infrastructure in all universities, the universities in the country in general were falling behind their students in terms of their use of new technology. Students in Saudi universities have begun using existing technology such as social networking sites to interact with their peers. Universities still have not benefited sufficiently from such environments, despite the government spending large sums to provide the universities with such environments.

Alhothili (2011) examined the use of Blackboard (Bb) at a university in Riyadh, using both questionnaire and interviews with students and staff. The study recommended reviewing the position of Bb at this university in order to benefit from it. This was because most students indicated that they were uncomfortable working with this system, and they did not know what the system offered. The staff expressed dissatisfaction with the lack of training and orientation, the complexities of the system, constant updates and modifications, and inadequate technical support.

In another study, Alghafli (2011) examined the use of Bb at a university in the Eastern Province. Nearly half of the lecturers that responded to a questionnaire of this study indicated that they were using this system. Most cited lack of knowledge on how to use this VLE as the main obstacle.

Mahdi and Al-Dera (2013) utilized semi-structure interviews and questionnaires to examine the impact of lecturers' age, teaching experience and gender on their use of ICT when teaching English as a foreign language (NFL) courses in a Saudi university. The findings revealed no significant difference in using ICT according to the lecturers' age and experience. However, the findings indicated a significant difference between male and female lecturers, with female lecturers reportedly falling behind their male counterparts in their use of ICT. Lack of training was found to be the main hindrance to better use of ICT by those NFL lecturers.

Most Saudi universities are using JUSUR as VLE. Some universities are using other VLEs as well, such as Blackboard and WebCT. Perhaps because the phenomenon of VLE is a new trend (Maashi 2009)—and in the early stages of implementation in most Saudi universities—these universities have not yet taken full advantage of virtual environments. Perhaps over time, these universities will benefit more from these environments.

1.6 Personal significance of the research

This research has personal significance for me. In terms of my background, I am a lecturer of mathematics at a higher education institution in the KSA. I am a committed lecturer and want the best for my students. As a lecturer, I have always tried to encourage my students to focus on their understanding of, and reflection on, mathematical concepts and to go beyond simple instrumentalism – or the carrying out of operations without understanding underlying principles.

Thinking back to my years as a student, with the exception of statistics lecturers in higher education, I do not recall coming across mathematics teachers in schools (during the 1980s and early 1990s), mathematics lecturers during my university years in the KSA (in the late 90s) or even during my subsequent master's studies in the United States (2000–2002) who used software in their teaching. The way I was taught had an impact on my views and on my practice as a new lecturer. I was also a non-user of software in my teaching. I thought that software should not be used when learning mathematics, except when handling a large set of statistical data. Other than that, I did not know how software could be employed to facilitate the learning of mathematics. Being a non-user of software was not a professional issue, as I was aware that many of my colleagues were not using software either.

When I reflect back on my practice as a lecturer, I felt an eagerness to focus on concepts rather than procedural techniques. I am not sure exactly why this was the case, but I was becoming aware of something going wrong in the teaching of the subject. Students were not as engaged as I had been as a learner, and seemed to see mathematics as a mechanical rather than an intellectual subject. Perhaps one reason for this was that the curriculum was largely based on textbooks written in formal and algebraic ways, and the summative assessment – the midterm and final exams – rarely tested for understanding. I remember always being in a 'hurry' as a teacher, presenting very abstract ideas in formal language and attempting to cover all the assessed topics within a very limited timeframe. In such a system, students have no choice but to focus more on procedural techniques because this is the only way they can 'survive' and pass the midterms and finals. As an example of this can be seen in my own personal experience: When I taught a basic concept such as the 'derivative of a function' in calculus, many students could not 'get the idea' that the derivative is a measurement of the tangent at each point along the graph of a function, as they were unable to clearly visualise the changes in the tangent. This was because the textbooks we used offered formal algebraic representations, with the visual dimension underemphasised or ignored. In retrospect, the use of software would have helped me to explain the concept of derivative more easily by helping my students to visualise the changes. This is perhaps one of the reasons why we observe that many students can 'differentiate' functions using rules learned in lectures or during controlled practice exercises, but the same students might not be capable of understanding the basic definition of the derivative.

My concern for the understanding of mathematical concepts created a tension in my practice; when I had a chance to pursue a PhD in the UK, I felt that this would be a golden opportunity to study the possibilities and constraints of using mathematical software as a means of facilitating the learning of mathematics. This later emerged as a study about the take up of ICT and mathematical software and the study became an attempt to explain the reasons for the very low use of software in the teaching and learning of university-level mathematics at a time when technology was increasingly used in the wider world. As such, the choice of the topic of this research was triggered by tension in my personal practice and a desire to help me understand how to improve my teaching, as well as teaching in my country as a whole.

1.7 Thesis Structure

My thesis consists of seven chapters. Chapter one is an introduction and the context. This chapter presents a brief overview of the study and includes an introduction to the study and its background, the purpose of the study, the research context, objectives and research questions, personal significance of the research and a basic outline of the thesis. Chapter Two provides a review of literature related to the use of mathematical software and the teaching of mathematics. Chapter Three explains the mixed methods methodology in this research and provides a justification for the use of interviews and surveys. Chapter Four gives a detailed analysis of the findings obtained from interviews, and Chapter Five presents an analysis of the survey data. Chapter Six comprises two parts. The first part integrates the findings obtained from interviews and questionnaire and explicitly addresses the five research questions, drawing in relevant literature. The second part explores the lecturers' take up of ICT through the lens of the Zone Theory associated with Valsiner. Chapter Seven provides an overall summary, and provides recommendations for further research.

Chapter 2 Literature Review

This is an eclectic review of literature on the use of information and communicational technologies (ICT), especially the use of mathematical and statistical software, in the teaching of mathematics at the university level. In this review, the goal is to look qualitatively at different uses of software, as well as the rationale for the use (or non-use) of ICT in mathematical classrooms at universities.

In my search, I used wide-ranging and cross-disciplinary sources including books, journal articles and conference proceedings. Primarily, I used educational databases on the E-recourses of the University of Warwick library's catalogue, such as Education Research Complete, a comprehensive search engine that allows users to enter double or triple key words. For example, one can make a query with the joint keywords: mathematics, ICT and undergraduate. I also used general search engines such as SpringerLink and Google Scholar. All of the chosen resources are high-quality sources, mostly consisting of peer-reviewed papers or books by well-known experts on the subject. When I started reading a considerable number of educational studies relevant to this subject, I found that some researchers have been very active in the area of mathematical software use in the teaching of mathematics in general (i.e. not limited to university-level studies). There were two groups of active researchers in this particular area: the British group, namely, Hennessy, Ruthven, Brindley and Kaput; and the French group, namely, Lagrange, Artigue, Laborde and Trouche. Whenever I found a valuable study, I proceeded in two directions: first, I conducted a query using the author's name to find other studies by the same author, and I often found that more than one study had been conducted by the author in question. Second, I checked the references list to search for other relevant studies. It should be noted that in such an extensively searched topic as the use of ICT in mathematics, when accessing the literature there is a variety of studies on mathematics teaching and ICT. There were certainly systematic reviews in existence (e.g. Buteau *et al.* 2010 and Lagrange *et al.* 2003). However, the findings of these papers should not be taken as applicable in all contexts. In particular, it should not be assumed that a study conducted in the United Kingdom or the United States will be applicable in a completely different context such as Saudi Arabia, or that the results of a study that took place in the 1990s will remain valid in the year 2014, especially in a rapidly evolving area such as the use of ICT in the teaching of mathematics. Also, there is literature on the use of ICT in higher education in Saudi Arabia, but not in mathematics teaching in particular. The important point here is that whenever there is a study on the use of technology in learning and teaching of mathematics in some stage of pre-university education, I need to look carefully at the findings of such a study to determine the possibility of applying such findings to the context of universities, which is very different from the school level.

This review is organized as follows:

2.1 Mathematics and Mathematics teaching

-The nature of mathematics

-Theories of learning

2.2 Mathematics and ICT—An Overview on ICMI's Studies

2.3 The Impact of ICT on Mathematics Education

-The impact of ICT on learning

-The impact of ICT on teachers and teaching practices

-The impact of ICT on curriculum

2.4 Factors Influencing the Adoption of ICT

-External factors—access, training, support

-Internal factors—beliefs

2.5 Ways of Understanding the Take up of ICT

-Models of users' acceptance

-Three zones model

-Activity theory

2.6 Reflection on the literature review

2.1 Mathematics and Mathematics Teaching

The nature of mathematics

Mathematics is both an abstract and practical subject. As reported by Al-Khateeb (2011), although there are diverse views on the nature of mathematics, with no common or generally accepted definition of it as a discipline, mathematics can be viewed as one or a combination of the following:

1. Mathematics is a (logical) way of thinking. In mathematics, one starts from 'accepted as true without proof' statements (axioms or definitions) and deductively ends up with 'justified' conclusions (theorems, lemmas (pre-theorems) and corollaries (post-theorems).
2. Mathematics is a universal language with known standards, expressions and symbols.
3. Mathematics is the study of formal structures by means of proofs (e.g. groups, rings, fields and vector spaces).
4. Mathematics is the study of numbers and symbols (e.g. quantities, relationships, formulas and equations).
5. Mathematics is the study of patterns in order to generate conjectures that can be validated via mathematical proofs.

The lack of a common definition of mathematics may be attributed to the diversity of the sub-fields under its umbrella. For example, in the current version of the Mathematics Subject Classification (MSC 2010), produced by the editors of two major mathematical databases (namely, Mathematical Reviews and Zentralblatt MATH), mathematics is divided into 97 main disciplines (e.g. 03-mathematical logic and foundations, 15-linear and multi-linear algebra, 62-statistics, 65-numerical analysis, 90-operations research, 97-mathematics education) (see **{** HYPERLINK "http://msc2010.org/mscwiki/index.php?title=MSC2010" **}**). Hersch (1997) argues that what determines whether a branch of study is a part of mathematics is more a question of its methods than content. If the methods are conjectures or proofs (as opposed to experiments in physical science, for example) then the sub-field is a part of mathematics.

Mathematics is involved directly in our daily lives and has applications in all walks of life. For example, mathematics plays an important role in all scientific studies as mathematical formulas help to design experiments and analyse data. Moreover, all social sciences and humanities, such as economics, psychology and sociology, rely on statistics, as is also the case for manufacture, commerce, medicine and other disciplines.

Ernest's three philosophies of mathematics

Ernest (1989) introduced three different philosophical views of mathematics, namely the instrumentalist, Platonist and problem-solving views of mathematics. In the instrumentalist view, mathematics is seen as an accumulation of facts and rules, which often operate in discrete fields. In the Platonist view, mathematics is described as a static but unified body of knowledge. And in the problem-solving view, mathematics is seen as a dynamic and constantly expanding field located in a social context. Ernest asserts that these three philosophies of mathematics can be seen as forming a hierarchy in which the instrumentalist view is the lowest, followed by the Platonist view, with the problem-solving view being the highest.

Ernest (1989) claims that these differing beliefs of mathematics have a great influence on the ways in which mathematics teachers approach teaching. He provides a model of the relationship between teachers' beliefs and their impact on teaching practices. According to his analysis, the practice of teaching mathematics depends on a number of key elements, most notably: the teacher's system of beliefs concerning mathematics as a subject and its teaching and learning; and the social context of the teaching situation, particularly the constraints and affordances it provides. Two teachers may have similar background knowledge of mathematics and teach similar mathematical courses, but while one teaches mathematics with a problem-solving orientation, the other has a more didactic approach. Beliefs are one reason for this variation. The key belief components of mathematics teachers are the teachers' views of the nature of mathematics, their views of the nature of mathematics teaching and their views of the process of learning mathematics.

Ernest (1989) stresses that teachers' views of the nature of mathematics are likely to provide a basis for the teachers' mental models of the teaching and learning of the subject. This means that mathematics teachers holding instrumentalist views would probably consider themselves as instructors, and focus on transmitting mathematical skills and procedures. Mathematics teachers holding Platonist views would likely consider themselves as explainers, and focus on conceptual understanding, taking a holistic approach and trying to link concepts together. The role of learners in both the instrumentalist and Platonist views relates to the reception of knowledge, where the former focuses on skill acquisition, and the later focuses on conceptual understanding. As for teachers who hold a problem-solving view of mathematics, they would likely consider themselves as facilitators, and try to guide learners to actively construct their knowledge.

Tall (2004) presented a useful way to categorize mathematical objects, activities and representations when he introduced his theory of the three worlds of mathematics: the embodied, symbolic and formal worlds. These worlds represent fundamentally different ‘kinds’ of mathematics. They differ in the types of objects, languages, operations and methods of proofs. The embodied, or sensory, world is where visual (or other) senses can be used to ‘visualize’, or create a mental image of, mathematical objects. The symbolic world is the world of numerical calculation and symbolic manipulations; he also called this world the ‘perceptual’ world since mathematical symbols are used as both ‘processes’ and ‘concepts’ (e.g. 3/4 as a process of division and a concept of a fraction, and dy/dx as a process of differentiation and a concept of a derivative). The formal, or axiomatic, world is where mathematical theorems are derived from axioms through formal deduction.

Tall (2004) argues that a mathematical statement is validated in the embodied world through visualization, in the symbolic world through calculation and manipulation, and in the axiomatic formal world through formal deduction and proofs. Take the notion of a differentiable function in calculus, for example: a function is differentiable when its graph looks ‘locally’ straight. In the symbolic world, a function is differentiable when we can calculate its derivative using symbolic manipulation, while in the formal world we use a formal proof starting from the definition to prove that a particular function is differentiable.

Tall (2002) suggests that one can see these three worlds in the way mathematics is taught in schools and in higher education. In primary school mathematics, the focus in the early stages is on embodied mathematics. At the final stage of the primary level and the early stage of secondary school, mathematics curricula are dominated by symbolic mathematics. Formal mathematics is introduced first in secondary school, and then dominates the mathematical curricula at most universities. At the university level, in pure mathematics courses (e.g. algebra, analysis and topology), the focus is entirely on the formal world, whereas in computational mathematics courses the emphasis is more on the symbolic and embodied worlds and less on the formal world. These three worlds are related. For example, Cayley's Theorem provides a connection between 'groups' (in the formal world) and 'sets' (in the symbolic world), and Representation Theory provides a connection between 'groups' (in the formal world) and 'matrices' (in the symbolic world).

Theories of learning

Over the past 50 years, psychologists and educational researchers have found ideas such as Dewey's inquiry-learning, Piaget's constructivism, Lev Vygotsky's social constructivism and Bruner's discovery learning useful. As a result, many educators believe that learning is not something straightforward, where teachers can simply pump information into the heads of learners, but instead, learning is an active process where learners establish a new understanding of the world around them through discovery, experience, active discussion and reflection. Learners do not simply receive ideas, but also build ideas on their own (Laurillard 2006).

Educators view the learning process from different perspectives, resulting in many theories that explain the learning process. Next, I will summarize the major theories of learning, namely, behaviourism, cognitivism and constructivism, and their implications in teaching strategies.

The first perspective is behaviourism. According to Mergel (1998), behaviourism focuses on behaviours that can be observed and measured objectively, and tends to ignore mental activities. Behaviourists view the mind as a 'black box' and believe that behaviour is the result of stimulus-response associations. Behaviourism focuses on the cycle of repetition of a behavioural pattern and receiving reinforcement (feedback) until that pattern of behaviour becomes automatic.

There are many examples of teaching models that are largely based on the behaviourist theory. The behaviourist model manifests itself more generally in activities that use a drill and practice approach, such as learning routines and procedural skills in mathematics. B.F. Skinner's work gave the theoretical basis for what are now known as educational kits, which have been used widely as a form of individual learning packages. Instructional software (courseware), or what is known as computer-based learning, is based on the behaviourist model. In a further example, the so-called Keller Plan—named after its founder Fred Keller—is a model of teaching based on behaviourism, and is used especially in higher education. The Keller Plan is a system of instruction that emphasizes that all students can master the material if they are given appropriate conditions and enough time. It is based on the idea of 'mastery learning', in which students can achieve the highest level of performance or 'mastery' if the conditions of their learning are controlled. Human intervention in the Keller Plan occurs through individual discussion between teachers and students following short quizzes in which students' learning difficulties are diagnosed. The Keller Plan has been more influential in subjects that have accumulated content, as in the case of mathematics courses (Boud 2006).

Unlike behaviourism, cognitivism opens the black box of the brain, emphasising the mental processes behind behaviour. Cognitivists focus on how information is processed, stored and retrieved in the brain. Jean Piaget theorised that new information is processed in three stages: a sensory stage, a short-term memory stage and a long-term memory stage. Cognitive theorists like Piaget believe individuals acquire knowledge through biological maturation and by engaging in learning activities within the context of the learning environment. Knowledge comes from applying what a learner already knows to new situations (Mcleod 2007).

More recently, Robert Gagne presented an amended view of cognitivism. In his seminal book 'Conditions of Learning', first published in 1965, he proposed a classification system of different types of learning based on the complexity of the mental processes involved. Arranging them in a hierarchy, he introduced eight basic types of learning activities. The lowest four (signal, stimulus response, chaining and verbal learning) focus more on the behavioural aspects of learning, while the highest four (discrimination, concept learning, rule-principle and problem-solving learning) focus more on the cognitive aspects. Gagne also presented his highly influential nine-step process of instruction (or 'nine events of instruction'). They are as follows: gaining the learner's attention, informing the learner of the objectives of the lesson, recalling prior knowledge, presenting the content, providing guidance for learning, eliciting performance, providing feedback, assessing the learner's performance and enhancing retention and transfer. He believed that learning is not a social event; rather, learning is an individual task (self-learning).This does not contradict the fact that people need some forms of help to learn and different learners may need different amounts of educational assistance (individual differences). Gagne's theories influenced the foundation of the instructional design field, and his ideas were used as a theoretical basis for designing computer software (Abu Asaad 2010; Al-Khateib 2011).

Constructivism is based on the assumption that learning is an active process in which learners interact with the world and construct their own meaning based on their own experiences. Constructivism emphasizes that the process of instruction should support constructing, not acquiring, knowledge. This doctrine has two versions, namely: 'cognitive (individual) constructivist' that stretches back to the work of Piaget; and 'social constructivist' after the sociocultural theory of Vygotsky. However, one of the drawbacks of the constructivist approach, according to Laurillard (2002), is that while it is theoretically acceptable, it does not provide details about linking teaching, student activity and interaction with the subject.

Megel (1998) stresses that both behaviourism and cognitivism support the practice of determining learning objectives, setting measurable outcomes, breaking tasks into small components, directing the learner, providing meaningful feedback and measuring performance based on the objectives. In constructivism, on the other hand, while the focus is on making sure that the environment is learner-centred and authentic, learning experiences are more flexible and less measurable, and methods and learning outcomes may vary from one learner to another. As a result, constructivism can find a better home in less centralized, less intensive curricula, provided that teachers enjoy more autonomy with sufficient timetables to give lessons.

To sum up, in this part of the review I discussed the nature of mathematics and introduced different philosophical views of it. Three major learning theories and some of their implications in teaching practices were also introduced. As discussed, mathematics is a broad subject with many diverse sub-fields under its umbrella. This diversity has made it difficult to reach a common definition of mathematics. There are different philosophical views of mathematics. As Ernest (1989) points out, mathematicians have three different views of mathematics: instrumentalist, Platonist and problem solving. Ernest's work suggests those beliefs about mathematics affect beliefs about learning, teaching and the use of curricular materials in mathematics. Ernest's work also suggests that these systems of beliefs will affect the practice of teachers in the classroom. One implication is that the contribution of ICT needs to be seen in relation to these ideas. Another implication is that what teachers believe may affect what they see as the affordances of ICT. Tall's (2004) work on the three worlds of mathematics provides a useful way to classify mathematics into different worlds in terms of the languages, objects, representations and methods of proof used. ICT can make a contribution in linking these three worlds with each other. This is related to the value of ICT in representing mathematical ideas in different representations, which will be discussed further later in this chapter. With respect to the learning theories, discussing them and understanding the strengths and weaknesses of each is important because they give different perspectives on what teachers do and the impact of what they do. They also give different perspectives on how the curriculum is constructed and what role ICT can play.

2.2 Mathematics and ICT

In this section, I will present an overview of the state of the current research regarding the use of ICT in mathematics education. Two reports undertaken on behalf of the International Commission on Mathematical Instruction (ICMI) and the Congress of the European Society for Research in Mathematics Education (CERME) will be discussed. One of the main reasons for choosing these particular reports was because they are primarily focused on the theoretical side, which remains active, of the use of mathematical software in mathematics education. These theoretical contributions have been made by a group of the most active researchers in this area, and they focus on the triangular relationship between learners, teachers and technology, and how each one of these affects and is affected by the other two, without ignoring the wider social and cultural context of school or university communities.

An Overview of the ICMI's Studies

Researchers in mathematics education have long studied the impact of ICT on mathematics and its learning and teaching. A study carried out by the ICMI, starting in 1985, was devoted to the impact of technology on mathematics and its teaching at university and upper secondary levels. In this study, there was considerable optimism about the future role of technology in mathematics classrooms, especially when computers become faster, cheaper and more accessible (Lavicza 2010).

Two decades later, the 17th ICMI study, edited by Hoyles and Lagrange in 2010, entitled 'Mathematics Education and Technology-Rethinking the Terrain' was published. The study aimed, among other objectives, to consider what had been achieved over the past two decades in terms of the impact of ICT on the teaching and learning of mathematics at the university level. The study suggested that the there was little evidence of any major impact of technological tools on the mathematics curricula of secondary and post-secondary education over the 20 years from 1985 to 2005.

Some of the main findings made by Maschietto and Trouche (2010), reporting on the discussion document of the above ICMI study, were that:

- There was a need to fill theoretical gaps, which had become clear in the past few years, to reflect the complexity of the relationship between education and technology.
- The impact of the use of technology in teaching and learning of mathematics was not self-evident. Its positive impact was questioned. A distinction was made between the actual and potential uses of technology. Developing wider use of technology was influenced by both access and social-cultural issues.
- Key challenges remain. One issue was how to design learning tasks in which information technologies, with their affordances and constraints, are integrated. A further issue concerned the balance between the use of mental, 'chalk and talk' and ICT tools. Another was assessment.
- The integration of digital technologies into teaching situations is a daunting and complex process. This is because they alter the existing equilibrium of the teaching situations; therefore, for successful adaptation teachers need to engage in carefully designed continuing professional developments (CPD).
- To analyse the role of teachers in guiding (orchestrating) technology integrated mathematics learning, different frameworks, drawing from both theoretical and empirical studies, are currently employed. This is closely linked to the notion of 'orchestration' from the instrumental genesis theory.

Laborde and Strasser (2010) offer a wider review of ICMI's studies and ICME's conferences during the past 25 years:

- Research has shown the complexity of integrating technology and raised important issues such as the mediation of mathematical content through technology, the changes in ways of solving problems using technology, the differences of the conceptual and practical activities in the classroom when technology is involved and the necessity of changing learning tasks.

- Technology has the potential to change the curriculum, including contexts such as: modelling or processing data in statistics; experimenting in algebra, geometry or statistics (spreadsheet, dynamic geometry); and visualizing in geometry. In practice, this catalytic impact is rarely observed.
- When ICT is used extensively in mathematics classrooms, the teacher's role changes to become more of a stimulant, a manager for learning or an orchestrator of the interactions between technology and student. The theoretical frameworks of studies on teachers' use of technology in their classrooms are often situated in a socio-cultural approach, in which interactions among students and between teachers and students are critical.
- The research shifted its focus from an individual learner doing mathematics with software towards theoretical and empirical studies that take a wider view of teaching and learning (e.g. activity theory, community of practice).
- There was a need for more research that focused on the pivotal role of the teacher in the learning process, and in particular, research that analyses the relationship between the teacher and the technology. Easy access to ICT does not guarantee that teachers or learners will use it.
- Merely analysing the artefacts (computers, software and communication technology) is not enough to understand how technologies will be used in teaching and learning mathematics. It is only the analysis of the instrument, i.e. the interaction of the artefact and how it is used (by teachers and students) that will assist in the implementation of ICT in the mathematics classroom.

Some of the themes surrounding the work of ICMI were further developed by a working group of the CERME, namely Working Group 9 at CERME4 (Barzel *et al.* 2005a). Their framework for understanding the use of technology was based on a triangle of influences that affect and are affected by each other in a reciprocal way. At the vertices of the triangle were: students, a teacher and tools (the group's focus was on IT tools). The significance of this triangular model is that it focusses on interaction between students, teachers and a tool, and raises questions such as: what are the factors that could affect such an interaction? What are the strategies for effective teacher training programs? And what types of pedagogical resources and technological tools are necessary for constructive interaction?

Regarding the nature of the interaction between the student and the tool, the report stressed that it is a two-way relationship where the tool affects the learner's thinking, but is also influenced and shaped by their thinking. The report found that the instrumental approach has been the most influential theoretical framework. In particular, instrumentation was recognized as powerful and promising with regard to explaining the nature of the relationship between the learner and technological tools.

With respect to the interaction between the teacher and technological tools, the report asserted that the notion of instrumental orchestration, which manages the process of students' instrumental genesis, provides an opportunity for effective teaching in a technology-rich environment. In order to effectively integrate technological tools in mathematical classrooms, the report stressed that there should be more collaboration between teachers with shared objectives. Teachers need to engage in continued teacher training workshops involving specific learning tasks, utilization schemes to solve such tasks and models of well-managed and productive orchestrations. The report also called for more research focused on the changing role of the teacher in learning environments that are increasingly dependent on information technology.

Regarding pedagogical resources, the report stated that it is the task, not the technology, which enables teaching to be effective. And the opportunities and constraints of the artefact guide learning, and therefore should be part of the designer's focus. On the issue of establishing a community of practice within the classroom, again the report asserted that the notion of instrumental orchestration is fruitful in this regard. It stresses that instrumental genesis should not only be an individual, but rather a collective process with the teacher as an 'orchestrator'. The report called for more research on instrumentation and orchestration, and suggested the need for linking this theoretical framework with other approaches, such as activity theory.

About the characteristics of the (technological) tools, the report pointed out that IT tools provide flexibility in the transition between the various mathematical representations, and help to facilitate the crossing of the border between researchers and those interested in the various branches of mathematics. They also enable students to 'do things differently and do different things', and they open the door wide for further discoveries, opportunities and challenges.

With regard to the criteria by which we know whether technological tools are useful in mathematics education, the report pointed out that one of the important criteria is: 'the tool should not take away responsibility from its users'. In other words, the user should be in full control of the whole process and a 'good' tool must not replace mathematics teachers, but should facilitate their work. In that sense, a tool should not be treated as a 'black box' since this would not promote the critical thinking that is essential in mathematics. A second criterion is that the technological tool should be easy to use because users here are specialists in mathematics, not programming. In addition, a tool should provide the user with immediate and high-quality feedback at every step when performing calculations or implementing algorithms. Another criterion is that the mathematical knowledge from the technological tool should be represented in traditional and standard mathematical notations in order to reduce the burden on the users when moving from one mode of representation to another.

The report classified digital media in a way that reflects the main sub-majors in school mathematics, namely, algebra, calculus, geometry and statistics. There are tools for programming (e.g. Logo), for graphing (e.g. graphing calculators), for dynamic geometry (e.g. Cabri, Sketch Pad), for algebra and calculus (e.g. CAS) and for data handling and statistical analysis (e.g. Excel, SPSS). Finally, the report called for special emphasis and further studies on the 'C' (communication) part of the term 'ICT'.

The ICMI's studies and CERME's reports outlined above raised many of the emerging issues on the complex relationships between the use of technology and the teaching and learning of mathematics. In particular, the idea of 'instrumental genesis', which involves the progressive process in which an abstract 'artefact' evolves into a useful 'instrument' used as a mediator in a learning activity, has emerged as a promising theory regarding the nature of the interaction between learners, teachers and tools in a technology-rich environment. Here is a brief description of instrumental genesis.

Instrumental genesis

Drawing from cognitive ergonomics and focusing on learning use of (technological) tools, a group of French mathematics educationalists, namely Artigue, Lagrange, Guin and Trouche (see Lagrange 1999; Guin and Trouche 1999; Artigue 2002) applied the idea of instrumentation to the learning of mathematics using ICT. The instrumental approach differentiates between an artefact and an instrument. For instance, a hammer has no meaning to a person who has not used one or watched someone else use one before. Initially, the hammer is simply an artefact. When the user is able to develop the necessary skills to use it in an effective way, and when he or she knows the right conditions in which the hammer will be useful, then and only then is it called an instrument. Such a process in which an abstract tool, an artefact, evolves into a useful instrument is known as instrumental genesis. Instrumental genesis is a complex process, linked to the properties of the artefact (its capabilities and limitations) and to the user's knowledge, activities and previous working methods (Drijvers and Herwaarden 2001; Trouche 2004).

Drijvers and Herwaarden (2001) discuss the association between the tool, the user and the task. The user has to develop skills needed to use the tool to perform specific tasks, and also has to determine for what kind of tasks the instrument is suitable and how this could be dealt with. The term 'instrument utilization schemes' refers to the 'how' part of the previous sentence. The development of these schemes is an essential part of instrumentation. An instrumentation scheme consists of more than a technical set of procedures that one carries out on a device to obtain a certain goal; it also covers a conceptual part, which is composed of the relevant mathematical objects and the problem-solving strategy. Such mental mathematical conceptions are part of the instrumentation scheme, and can grow even more while implementing the scheme.

Within the instrumentation scheme, technical skills and algorithms are closely and inseparably linked with conceptual insights. If we take this conceptual part into consideration, it is not surprising that the instrumentation process does not occur automatically and without problems. Consequently, for a teacher who uses ICT in mathematics teaching, giving specific attention to the development of instrumentation schemes can be useful. And the notion of instrumentation can also be useful when attempting to understand the difficulties met by students. Thus, instrumentation of technological tools refers to the association between mathematical concepts and technical skills, and both are involved in the acquisition of instrumentation schemes, which are at the core of instrumental genesis (Drijvers and Herwaarden 2001).

2.3 The Impact of ICT on Mathematics Education

In the context of addressing issues related to the use of ICT in teaching and learning mathematics, many authors (e.g. Drijvers and Herwaarden 2001; Bretscher 2008) have identified a general pattern—one which begins with high hopes and ends with disappointment concerning the very limited use of technological tools. This suggests that integrating ICT in mathematics education remains a complex process that requires further theoretical and empirical research. In order to shed light on what prior researchers reported on the reality and possibilities of mathematics education in the era of information technology, I will adapt the categories used by Ozgun-Koca (2010), starting from the impact of information technology on student learning, then its impact on teaching practices and finally its impact on mathematics curricula.

2.3.1 The impact on students' learning

In the learning and teaching of mathematics, there are two main objectives (Kutzler 2000). The first is to develop the ability to 'think mathematically' (Tall 1998), which involves the development of intellectual skills that are important in themselves and may help in solving technical problems in the real world, and the second involves solving real-world problems using mathematical models that can be solved using procedural techniques (e.g. developing algorithms, symbolic manipulation, numeric calculation, solving systems of equations, etc.). In order to achieve these objectives, two types of activities occur in mathematical courses: intellectual activities (theoretical classes) and problem-solving activities (exercises sessions). The former involve applying logical deductions to produce and justify new theorems on the basis of already established theorems or axioms, while the latter involve applying mathematical tools (proved theorems and procedural skills) to solve real-world problems.

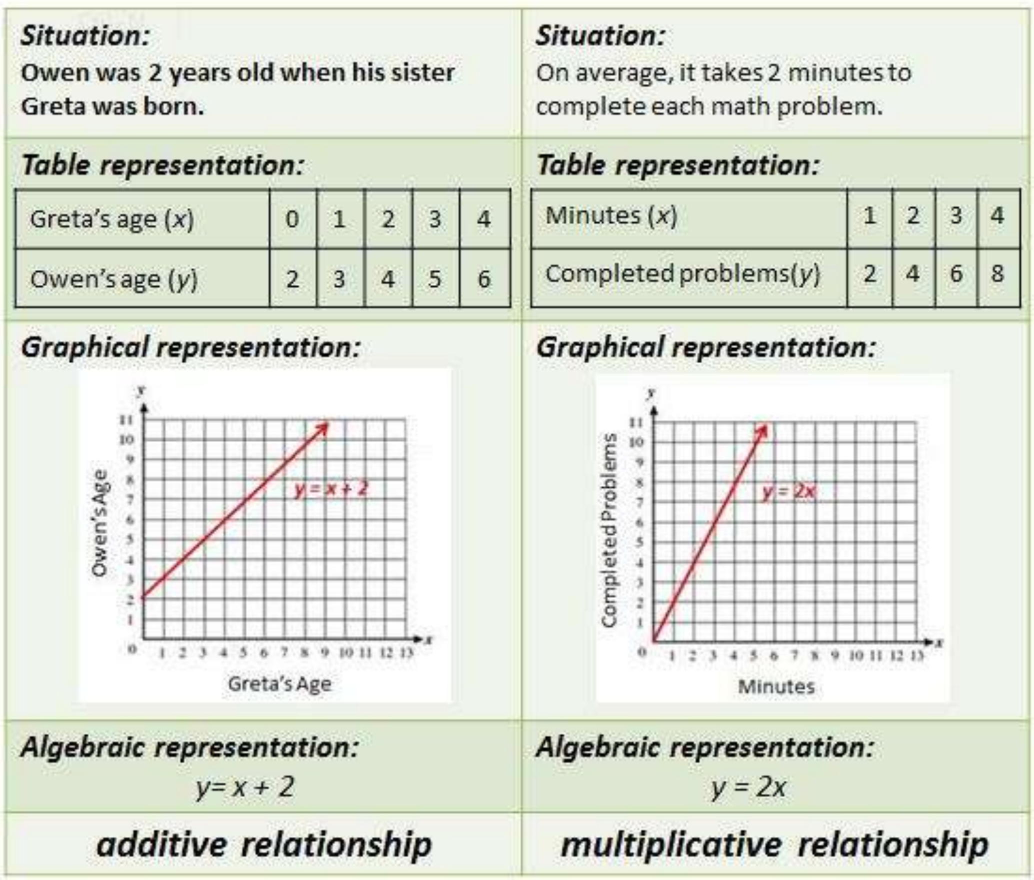
Kutzler (2000) discusses the three steps needed to solve real-world problems in mathematics. The first step is to construct a mathematical model of the problem and translate the problem from its original real-world language into the language of the model world. The second step is to solve (or calculate) the model using general procedural techniques and available algorithms. The third step is to translate the solution from the model world back into the real world. The first and the third steps are intellectual in nature and the second step is practical. Software can play a role in the execution of the second step.

Benefits of using mathematical software

The automated features of software are a major benefit when doing and learning mathematics. The essence of the impact of the use of ICT on mathematics education is, as Tall (1998) put it, that 'it highlights the difference between being able to perform standard skills and being able to think mathematically' (p. 66). In other words, the automated features of technological tools allow curriculum designers, teachers and students to focus more on the intellectual side of mathematics, reducing the focus on the procedural aspect, which may be of less importance, especially when performing routine computations. Edwards (2002) agrees with this point, stressing that thanks to technology learners can now learn mathematical topics at a higher level of depth without being hampered by procedural errors that may consume a lot of time and effort. In this sense, mathematical software can be considered as a facilitator to implementing procedural , time consuming and technical skills, while students are given more time to interpret the results (Peschek 2007) or study more complex topics (Stacey, Kendal, and Pierce 2002). However, at the Computer Algebra in Mathematics Education (CAME) Symposium in 2009, Berger (2009) argued that the use of CAS as a tool for computation is not always without consequences. For instance, as much as one may consider solving polynomials of the fifth order as daunting and mechanical, through such procedures one may gain conceptual knowledge about the characteristics and features of mathematical constructs. Thus, although the use of software eases the burden on students performing complex calculations, its excessive and thoughtless use could lead to a lack of understanding of some of the important concepts that are often learned while performing procedural computations.

Using different representations of the same mathematical object is one of the most important aspects of doing mathematics (Tall 2000). According to Tall's three worlds of mathematics, every mathematical object can be represented in three different modes: graphic, symbolic and numeric or formal. Multiple representation lies at the heart of most mathematics software. For example, CAS provide an interface for graphing, manipulating symbols and finding roots for equations. Figure 4 shows a simple example of two different functions ($y = x + 2$ and $y = 2x$), and three different representations of each (algebraic [function rules]), graphic (diagrams) and numeric (tables) (SciMathMN and the Minnesota Department of Education 2013)

Figure 4: different representations of $y = x + 2$ and $y = 2x$



The value of such representations has been shown in several studies. For example, Barzel (2007) found that students and teachers positively evaluated the contribution of CAS to learning the concept of 'function' in calculus. In particular, they positively assessed the role of CAS in enabling a quick shift between symbolic, numeric and graphic representations of functions (i.e. representing a function with an equation, a table of numbers and/or a graph). As such, a rapid alternation between various representations of mathematical ideas is usually seen as a step forward towards a deeper understanding

(Gjone 2009). This is, as Barzel (2007) suggests, perhaps because these different representations address the diverse preferences of individual students.

The notion of multiple representations leads to Skemp's notions of 'instrumental understanding' and 'relational understanding' (Skemp 1976). The former is characterized by the ability to memorise certain rules and execute them without knowing the logical justification behind them , whereas the latter can be described as knowing how to deduce a rule (either implicitly or explicitly) as well as how it works. By definition, a relational understanding is the ultimate goal of mathematics education, and in order to achieve this goal teachers need to guide their students in linking concepts with procedures and justifying each step of the procedure starting from the given all the way to the conclusion.

Duncan (2010) conducted a project involving 6 Scottish secondary schools, 2 mathematics teachers from each school (a total of 12 teachers) and students from different ages and stages. Teachers used TI-Nspire PC software and students used TI-Nspire handheld technology. The findings of this study revealed that all the teachers were convinced that the use of multiple representations of mathematical concepts (using TI-Nspire) enhanced their students' relational understanding of these concepts.

Researchers in mathematics education stress the important role played by mathematical software in assisting visualization of abstract mathematical concepts. For example, Palais (1999) asserts that individuals who need to use mathematics, but are not completely at ease with mathematical formulas in abstract (formal) representation, can better understand these concepts if they can visualize them. Tall (1991) emphasizes that students need to be trained to think visually in the same way that expert mathematicians do, and he claims that graphing technology plays a powerful role in enabling learners to overcome their shortcomings, especially when dealing with complicated mathematical concepts. In a large survey of findings of published research about graphing technology from Michigan State University (Burrill *et al.* 2002), most researchers reported that students use handheld CAS-equipped calculators for one or more of the following: computation, multiple representations (numeric, graphic and/or symbolic) and visualization. Handheld graphing calculators are primarily used to graph functions.

Giaquinto (2007) further emphasises the importance of visualisation, even if he recognises it is not considered as a valid proof. Visualization is useful in several aspects. For example, it is extremely useful as a means of discovery towards establishing formal proofs, especially in the initial stages, and it is useful for verifying the correctness of the proofs afterwards. It is also useful because it helps to grasp the validity of a method when solving a problem and helps in understanding why the method is correct. In addition, Tall (1998) explains the epistemic value of visualization in the gradual growth of a sophisticated mathematical theory. He stresses that software can provide an effective means of manipulating (e.g. rotating, zooming in, zooming out) visual objects. This in turn allows for strong 'sense making' of subtle concepts at a primitive level, and subsequently this can provide what is described as the 'root of knowledge' through which the gradual growth of an established theory occurs. This can happen not only in geometry but also in various fields in mathematics.

Attorps *et al.* (2011) conducted a quasi-experimental study entitled 'The use of mathematics software in university mathematics teaching'. The experiment aimed to examine the effectiveness and the possibility of using the free mathematical software GeoGebra as a pedagogical tool when teaching the concept of definite integrals in calculus. The experiment involved using the software to perform numerical approximation of the area of the lower and upper Riemann sums and letting students visualize the areas of the two sums. The dynamic features of the software enabled students to increase the number of subintervals in order to minimise the difference between the two sums to obtain a better approximation of the value of the integral. Further, the software was used to distinguish between cases in which the theory could be applied and other cases in which it could not be applied. The experiment revealed that it is possible to use the features of GeoGebra effectively when teaching calculus to provide fruitful learning opportunities and let students experiment with the intended object of learning.

While mathematics educators have emphasized the value of information technology as a powerful tool to visualize abstract and complicated mathematical objects, some researcher have expressed concerns in this regard. For example, Booth and Thomas (2000) argue that the role of visualization in understanding mathematical concepts remains unclear despite much research on this particular issue. And Haciomerogln, Aspinwall, and Presmeg (2010) present examples of derivatives and anti-derivatives of graphs (from calculus) to demonstrate that sometimes utilizing visual images only, without using analytical thinking, may hinder mathematical thinking.

In addition to the automated features, multiple representations and visualization, there are other benefits reported in the literature. For example, Edwards (2002) mentions that symbolic manipulation software (CAS) offers students the benefits of traditional graphing calculators, and these tools can also be used interactively to enhance students' understanding of step-by-step symbolic manipulation. What differentiates CAS from the previous generation of graphic calculators is that with CAS, equations are solved symbolically, and for this users need to understand the symbolic notations of the software. Edwards also emphasizes that by using graphical methods, students are led to develop new skills in dealing with algebraic problems. Another point mentioned by Barzel (2007) is that CAS and other mathematical software are always available, whether on a PC or a handheld device (graphing calculator such as Voyage 200 or TI-89).

At the CAME 6 Symposium in 2009, Berger asserted that one of the most important uses of mathematical software as a tool of learning was that it could be used to generate numerous examples of a particular mathematical construct. From these examples, the student, in collaboration with his or her peers, may attempt to generate a hypothesis (or mathematical generalized statement) that needs to be proven later, perhaps by using paper and pencil. Generating examples is important because they allow students to move from special cases (various examples) to generalizations, which enhances students' mathematical sophistication. This would also make them practice mathematics in a constructive way similar to what a mathematician does in his or her research.

Drawbacks to the use of mathematical software

Researchers have not been slow in reporting some drawbacks when using mathematical software, including the black box of software use, where one simply performs a series of button presses without understanding the underlying concepts behind such actions. Tall (2000) points out that the use of software in mathematics was not always as successful as it should be. For example, the use of calculators in England, especially with younger pupils, has been discouraged in the hope that children will build strong intellectual foundations in mathematics, especially in basic arithmetic. Tall speculates that this may be the result of a fear of the misuse of technological tools, or the use of calculators without any mathematical thinking, and not due to any inherent defect in the tool itself. He stresses that calculators can be very useful for students' learning, if used to encourage thinking and reflection of mathematical ideas. On the other side of the Atlantic, Tall (1998) points out that the American calculus reform was based on the extensive use of technology, including a wide range of software that uses various representations (symbolic, graphical and numerical). However, there is evidence of many students' misuse of CAS (e.g. Hillel 2002; Paige, Seshaiyer, and Toda 2007) in a way that can easily impair their learning. An example of such misuse is students' use of CAS as a black box, leading to their inability to link the mathematical ideas in the same way as those using more traditional methods.

Further, students and teachers might encounter difficulties when studying or teaching with software, such as the inability to determine when and how to use the software. This is related to the debate of whether software is an artefact or an instrument (e.g. Drijvers and Van Herwaarden 2001; Artigue

2002). Students might believe that they will benefit from the use of software. Therefore, they may want to use software, but then the next question is how to use the software (Ozgun-Koca 2010).

In their review of past research, Burrill *et al.* (2002) point out that there were some concerns about IT readiness, not only in relation to the issue of access to resources, but also related to whether teachers and students were ready to use the technology (i.e. instrumental genesis). In a study by Bretscher of King's College (Bretscher 2008), in a sequence of five lessons, pupils from a year eight class engaged in a series of construction problems in pairs using the dynamical geometry software Cabri-Geometre. The study revealed that students had difficulties in understanding the concept of functional dependency in geometry. The study linked that to the conception of 'utilization schemes' in the theory of instrumental genesis. An important point in 'utilization schemes' is that technical and conceptual progress co-evolve, and it is emphasised that technical development should not precede conceptual understanding. The study recommended that teachers should highlight the constraints and limitations of the software to students in order to support their instrumental genesis. The notion of instrumental genesis and the difficulties teachers and students face in deciding when and how to use the artefact could explain the strong potential, but poor reality, of the use of ICT in classrooms, which most of the research findings generally conclude.

As we can see, there is a balance between the opportunities and constraints of using mathematical software. Among the opportunities are the automated features of the software, which help in saving a lot of time by allowing teachers and students to focus more on the intellectual side of mathematics and reduce their focus on routine calculations. The software also helps in representing mathematical objects in multiple ways and visualizing complex mathematical shapes. On the other hand, among the obstacles to the use of the software is the fear of it as a black box and the inability to determine when and how it can be used in a constructive way.

2.3.2 The impact of ICT on teaching practices

In its technology principle, the National Council of Teachers of Mathematics (NCTM) states: ‘Technology cannot replace the mathematics teacher, nor can it be used as a replacement for basic understandings and intuitions. The teacher must make prudent decisions about when and how to use technology and should ensure that the technology is enhancing students' mathematical thinking’ (NCTM 2013).

Bretscher (2009) points out that research on the use of ICT in mathematics education has tended to focus more on innovative usages and interaction between students and machines, rather than focusing on the teachers’ concerns. Reporting on ICME's conferences, Laborde and Strasser (2010) point out that starting from ICME 10 (2004), there was a shift in research focus from the learner to the teacher's dimension, taking into account the complexity of integrating ICT into mathematics, social dimensions and curriculum issues.

In the USA, Ertmer (2005) reports that although many teachers are using technology for low-level tasks (such as word processing and Internet searches), higher-level tasks are still rare. Ertmer emphasizes that ultimately change in classroom activities falls on the shoulder of the teachers. Thus, to achieve the desired change, educators need to explore the teacher’s dimension as well as increase focus on teacher input relating to teaching, learning, mathematics and technology.

As reported by Bergqvist, Holmquist, and Lingefjard (2004), the presence of ICT in mathematics classrooms can bring about a radical transformation in traditional teaching. For example, a teacher who wants to integrate mathematical software into calculus lessons might need to change the conventional algebraic approach to a more geometric approach based more on visualization when representing mathematical objects.

The use of software may require reconsidering teaching strategies and teachers’ preferences. With software, for example, teachers might focus more on finding patterns as opposed to procedural skills

(Ozgun-Koca 2010). This is because while teaching procedural calculations is important, the most important responsibility of mathematics teachers is to teach their students how to 'think mathematically' (Tall, 1998). Group discussion and cooperative work are instructional methods suggested to be used when software is utilized (Guin and Trouche 1998; Drijvers 2004).

In 2005, at the Fourth CAME Symposium, the teachers and CAS group discussion (Barzel *et al.* 2005b) asserted that teachers need to see software as a tool of learning and not just a tool to generate quick and easy answers. To help teachers integrate software into their teaching, it was suggested that teachers should be provided with tasks and lesson plans to build a more positive view towards the use of educational technology in teaching.

CPD is an important factor in developing the use of ICT. Appropriate CPD must help enrich teachers' vision of the potential of software and its role in the learning and teaching of mathematics. These training programs would help teachers to be more comfortable when dealing with software in their teaching, and they would be in a better position to analyse how to use the software in a constructive manner to enhance students' understanding (Littlejohn 2002; McCarney 2004).

TPCK can be used as a model of effective CPD for developing teachers' technological, pedagogical and content knowledge. TPCK, short for technology, pedagogy and content knowledge, was introduced by Mishra and Koehler (2006) as a model for technology integration in teaching. TPCK takes into account the interaction between three bodies of knowledge: content knowledge (CK), pedagogical knowledge (PK) and technological knowledge (TK). CK refers to knowledge of the subject matter to be learned or taught; PK refers to knowledge about pedagogy; and TK refers to knowledge of how to operate different technologies, including digital and communicational technologies. TPCK combines these three forms of knowledge in the context of learning environments and looks at how they work together to increase the likelihood of making the content more accessible to students. It involves selecting appropriate technologies to support the pedagogical strategies that have been identified as helpful in making the content more understandable.

Assuming that the software is a tool at the disposal of teachers likely to be used at any time, mathematical software can potentially have various roles in the teaching of mathematics (see Heid and Edwards 2001; Ozgun-Koca 2010). The first role that could be played by mathematical software in teaching is as a tool for speedy calculations. As seen earlier, this shifts the focus away from technical procedures towards conceptual understanding, problem-solving strategies and interpretations of results with appropriate support and guidance from the teacher. Secondly, software could be used as a black box. This happens when the software is used to provide the final result of the mathematical problem without showing the intermediate steps. Thirdly, software could be used in a white-box approach where solutions are executed step-by-step, allowing students to focus on the symbolic manipulations. Unlike the black-box approach, here there are no hidden steps throughout the process from the given until the conclusion. The use of the white-box teaching method first, before resorting to the black-box approach, could lead to an optimal outcome (Ozgun-Koca 2010).

Edwards (2002) points out that unlike many other CAS, the Symbolic Math Guide (SMG) application from Texas Instruments (2001) was designed specifically as a teaching tool. SMG enables students to manipulate algebraic expressions by selecting various transformations from menus within the application. To select useful transformations, students need to have a strong understanding of concepts as well as symbols. Because students can erase unsuccessful problem-solving steps, SMG encourages students to learn actively through experimentation.

Ozgun-Koca (2010) investigated the views of Turkish prospective secondary mathematics teachers on three possible uses of CAS in algebra instruction, namely, the black-box method, the white-box method or SMG. An open-ended questionnaire and group interviews revealed the participating teachers mainly preferred the white-box method, and especially SMG, to the black-box method. The majority of the participants believed the main benefit of the white-box method is the control that the students have over this methodology. Some participants shared concerns about the possibility that students might become too dependent on the technology. The results also showed that the participants believed that the black-box method could be used after students master the skills. The study suggested that even with the wider availability of CAS, they have not impacted the study of symbolic manipulation topics such as algebra and calculus to the same extent that graphing calculators have influenced the study of graphs. An interpretation of the results also revealed that teachers would like to be in control of their classrooms when using technology. They also need more experience and familiarity before they use software in their teaching.

2.3.3 The impact on mathematics curricula

Topics in mathematics can be represented visually (like in Euclidean geometry), symbolically (as in arithmetic, algebra or calculus) or formally (formal proofs). By providing students with visual and symbolic software, the use of ICT is challenging many popular notions of mathematics curricula (Tall 1998). The opportunity exists to focus less on procedures and routine tasks and more on understanding concepts and interpreting results (Ozgun-Koca 2010). With easily available software, one can generate solutions to differential equations, multiple integrals and all sorts of procedures in symbolic mathematics that previously would have taken a long time. Even in pure mathematics, in subjects such as group theory, one can compute group order, normalizers, centralizers, composition series and conjugacy classes of groups of finite order using a package such as Maple. An important point to make here is that it is not enough to give students the necessary tools to carry out these procedures if they are not properly integrated into the structure of the curriculum.

Edwards (2002) stresses that the strong capability of mathematical software requires curriculum designers to reconsider the roles of symbolic manipulation, graphing and procedural calculations. Technological tools compel teachers and curriculum developers to reconsider the types of problems that students are asked to solve. In particular, with the presence of such powerful tools it is recommended that curriculum developers reduce the focus on procedural problems that are solved directly and routinely and move towards a curriculum that is based more on real-life applications.

Further, as Fuchs (2001) points out, the introduction of mathematical software has affected the 'weight' of mathematical content. For example, the study of logic, algorithms and programming, which lie at the heart of computer science, has become relevant to mathematics, particularly to computational mathematics, a branch of mathematics that relies on developing algorithms to solve real-world problems. In another example, topics such as complex processes or dynamical systems have become accessible for younger students as they allow the simulating and modelling of systems and examination of the behaviour of these systems. Moreover, by integrating mathematical software in the curriculum, more student-centred and constructivist approaches to teaching can be facilitated (Heid and Edwards 2001). The teacher's role can be transformed from direct instruction to supervision and guidance. Furthermore, students can take on group projects and cooperate with partners in contrast to traditional roles in which the focus is on working individually to solve problems that are often 'mechanical'. Part of this change requires a new examination system in which students are allowed to use these technological tools (Fuchs 2001).

As seen, the presence of mathematical software in the mathematical curriculum can not only change and transform the content of the curriculum, but also has a major impact on the role of the teacher as well as on students' learning.

To implement a mathematical curriculum that involves the use of ICT, Sarama, Clements, and Henry (1998) stress that reformers should first acknowledge the complexity of the process. Teachers must be provided with enough time to engage in training programs that contain specific activities on how to use the new tools and the strategies used in these training programs should be built upon and recognize teachers' prior knowledge, beliefs and experience. Sarama *et al.* present a model of influences in the process of providing, designing, supporting and implementing the curriculum. These are discussed below.

The first social group is teachers. They are the principal agents that deliver the curriculum, and they have their own knowledge and beliefs about mathematics, about pedagogy (e.g. transfer of knowledge versus constructivism), about student learning and about software (e.g. computer literacy). An important point mentioned by Sarama *et al*. (1998) is that teachers come to innovation with different sets of ideas and experiences and thus vary in their knowledge and belief systems; teachers usually reject innovations that appear unrelated to the curriculum, especially when they are not comfortable with technology. The second social group is administrators and their views about the role of technology, teachers and designers. Administrators are the ones who provide the infrastructure for ICT (hardware and software, LMS, etc.), and provide on-going support for teachers, training and encouragement (by giving incentives, for example). The third group is curriculum designers (or developers) and their views about the role of the software and the role of teachers, and how they interact with teachers during curriculum design. The fourth group is the support staff who manage the resources and provide technical assistance in the teaching process. They have their own views about the role of software and the role of teachers. The fifth group is students, who are the target of the whole process. Students have their own beliefs about mathematics and about software, as well as their own preferences and competencies in learning mathematics with software. An important point to note is that within the broader social context that contains this network of influences, some of the social groups mentioned above might have more direct influence than others on the decision to implement software-assisted curricula.

The discussion about curricula can be explained in the more general context of Laurillard's (2002) very influential 'conversational framework'. Laurillard calls for a radical shift from the predominant transmission model of teaching to a system that enables students' active engagement with their instructors on many levels. She argues for moving beyond a curriculum that focuses on simply imparting facts and procedures to one that support the development of acquiring high-level sustainable cognitive and practical skills. She offers a model for reforming higher education, which is not achieved through the training of university lecturers on how to teach their subjects effectively, but rather through providing a system of 'organizational infrastructure' that enables high-quality, effective academic learning and teaching to be delivered.

Laurillard's strategy involves an 'iterative dialogue' between an academic teacher and his or her students on pre-defined topic goals. In this teaching strategy, there are three interrelated parts: firstly, there is a curriculum predetermined by sets of objectives; then there are learning activities created and 'mediated' by an academic teacher and carried out by students; and thirdly there is a rigorous system of assessments and feedback that facilitate and test the success of this process. The success, or otherwise, of teaching and learning depends largely on the intrinsic and extrinsic feedback that students receive from such dialogue.

According to Laurillard's conversational framework, for any learning situation to adapt a more desired progressive teaching model, there are sets of requirements:

- There are two active participants: the teacher and the learner.
- The dialogue occurs at two levels: theory and practice.

- There is a discursive process (discussion) at the level of theory and there is an interactive process at the level of practice.
- To move from theory to practice, the teacher need to adapt the learner's activities and the learner needs to adapt actions in light of discussion.
- Both participants need reflection in light of experience to modify description of theory.
- The interplay between theory and practice is essential in making abstract concepts concrete, which will facilitate understanding.

In Laurillard's view, technological tools are classified in terms of their support for the discursive-adaptive-interactive-reflective processes covered by the conversational framework. She identifies five media forms: narrative (e.g. print, images), interactive (e.g. search engines), communicative (e.g. email, discussion forums), adaptive (e.g. CAS) and productive (word processors, spreadsheets). According to this classification, posting lecture notes on the Web offers no more than doing a transmission model of teaching. Mathematical or statistical software, on the other hand, are adaptive types of media since the software gives intrinsic feedback in light of the user's input.

The importance of Laurillard's model, besides being an influential model in higher education, is that it exploits the potential of ICT in serving specific types of learning activity. ICT tools can provide different levels of support for different types of learning experiences. However, at the heart of learning remains the progressive dialogue between teachers and students; ICT cannot replace teachers in this pivotal role.

2.4 Factors influencing the take up of ICT

Many researchers have conducted general reviews (not necessarily focused on a particular subject or a particular stage of education) of issues that affect the use of ICT in teaching. These reviews have revealed a wide range of factors that either motivate or impede any sustainable use of ICT by teachers.

Hooper and Rieber (1995) examined the reasons why technology has not had a major impact on teaching practices and identified the conditions for achieving effective use of technology. They present a five-stage hierarchical model of the adoption of technology in teaching. These stages are: familiarization, utilization, integration, reorientation and evolution. It is likely that ICT will be misused or avoided unless teachers evolve through all five phases.

Familiarization occurs when a teacher has little acquaintance with a technology during the initial exposure to this technology. Utilization occurs when a teacher uses a technology in the classroom. Integration happens when a teacher allocates some of the teaching tasks to a technological tool so that if the functionality of this tool is disrupted, the teacher cannot proceed in teaching as planned. Reorientation requires teachers to re-conceptualize the function of the classroom and reconsider classroom activities to become student-centred. In addition, teachers and students should be involved in a triangular collaboration with technology to create a 'community' to support the process of learning. Perhaps for that reason, the teacher with a reoriented view of teaching will not feel threatened by being replaced by technology. Evolution is as a reminder that for an effective educational system, teaching must be constantly evolving.

Hooper and Rieber make a distinction between product technologies (such as hardware and software) and (intangible) idea technologies. Simulation and visualization are examples of idea technologies because they enable people to experience concepts that cannot be easily accessed. The distinction between product and idea technologies is important because most of the historical attempts to use technology in education were focused primarily on product technologies. Product technologies may be used to support the status quo of beliefs and practices of classroom teachers that were based largely on behavioural models emphasizing the transfer of predefined content. For an effective and sustainable use of technology in teaching, ideas as well as product technologies must be taken into account and teachers must dare to go beyond utilization and into the integration, reorientation and evolution phases of technology use.

Different classifications have been made of the factors that either encourage or discourage the use of ICT in teaching. For example, Ertmer (1999) classifies the barriers that prevent the introduction of technology in education into two main categories: external (first-order) barriers and internal (second-order) barriers. First-order barriers are those obstacles that are not difficult to be measured or eliminated. Usually, these barriers are related to the lack of or inadequate access to resources (such as hardware and software), time, training and support. Second-class barriers are the fundamental beliefs of teachers about teaching and learning and the role of technology. These beliefs may not be easy to measure and are often difficult to change. Ertmer goes on to point out that while some teachers are constrained by external barriers, including limited resources, inadequate training and insufficient support, others are struggling to overcome their own deep-rooted beliefs about the roles of teacher and student, curriculum and assessment focus.

In reviewing the literature on barriers to the uptake of ICT by teachers, Jones (2004) found that the main external barriers were lack of access to ICT resources, lack of time to integrate ICT, lack of effective training and lack of technical support, while the main internal barriers were teachers' lack of confidence, resistance to change and beliefs that there were no benefits to teaching with ICT.

Another perspective developed by Bingimlas (2009) presents a range of barriers that prevent the integration of technology and affect and are affected by each other in reciprocal ways on two levels: at the teacher level and the school level. Again, lack of access to resources, lack of enough time to plan and implement lessons that involve the use of ICT, lack of effective training, lack of technical support and resistance to change and negative attitudes towards technology were presented as barriers preventing teachers from utilizing ICT in their teaching.

Bingimlas asserts that for meaningful integration, all of these barriers need to be dealt with and eliminated at the school level as well as at the teacher level. For example, access issues can be resolved at the school level by providing appropriate resources with sufficient quantity and good quality, while teachers can overcome this issue by taking advantage of these resources. Resistance to change may be dealt with at the school level through providing on-going training programs for teachers with specific activities and plans for lessons using ICT, while teachers should be open minded to exploring new ways of teaching and benefitting from ICT tools and resources.

To investigate the factors causing such slow development of technology use in university mathematics, one cannot ignore the reality that most research on technology use in mathematics learning and teaching is focused on school-level mathematics as opposed to university-level mathematics, and there is a need, in a sense, to 'filter' the findings of such research to see to what extent they may be applicable to the very different contexts of university environments, or if they are peculiar to school-level mathematics (Laurillard 2002).

In school mathematics, Hennessy, Ruthven, and Brindley (2005) show that, other than the external factors such as accessibility and availability of technological tools and resources, curriculum and assessment requirements, the external pressure from policy makers, and 'lack of professional autonomy' (ibid, p. 57), it is teachers' competence and confidence in working with technology and their beliefs regarding the perceived benefits of incorporating technology into lessons that most influence the introduction of technology into core subject teaching, including mathematics . Lavicza (2007), however, suggests that, unlike school mathematics teachers, university lecturers are less subject to external pressure. They might also see teaching from the perspective of being a professional mathematician rather than a professional in pedagogy. Lavicza also feels that higher education lecturers have the relative advantage of being less restricted, and, unlike school teachers, if university lecturers decide to use ICT in their teaching, it means they hold strong beliefs about its importance because there is less pressure on them to use it. Another factor mentioned by Lavicza is that lecturers at universities have greater mobility as they collaborate and participate more in national and international conferences, and may be more influenced by other teaching traditions in other countries. It is also suggested that the main determining factor regarding the decision to use technology in university mathematics classrooms is the deep-rooted mathematical principles of mathematics lecturers and their strong ties to mathematics as a discipline, rather than their pedagogical views.

In the area of software use in tertiary mathematics education, the recent comprehensive review of 326 papers on the use of CAS in post-secondary mathematics education by Buteau *et al.* (2010) indicated that, unlike school-level literature where education research papers constitute the great majority of the literature, the majority of papers come from mathematicians reporting on technology-related teaching practices and only a small minority constitute specialized education research papers. Practitioners' papers include reporting on examples of the use of software packages and technology-related classroom studies without, or with only very limited, classroom data (e.g. Pointon and Sangwin 2003; Dana-Picard, Kirdon, and Zeiton 2008; Kosa and Guven 2008; McCabe 2009).

Buteau *et al.*, in their review, reported that CAS is more likely to be used in first-year courses, and especially in calculus. The review revealed diverse purposes for the use of CAS in tertiary classrooms.

Primary purposes are to visualize mathematical images using the projection technology with which many modern classrooms are equipped, to explore mathematical concepts and to use software for out-of-class assignments. Further, the review highlighted many possible obstacles to technology integration. Besides technical and financial barriers and time pressures on faculty, the most worrying issue in both secondary and post-secondary mathematics was the issue of assessment, which remained traditional (pen and paper). Another concern was the over-reliance on the software, which may weaken students' mathematical abilities, and a more general 'black box' view of mathematical software.

Goos (2005) reports that research on technology use by mathematics teachers has identified a range of factors influencing take up of ICT, including: access to ICT; beliefs about mathematics and how it is learned; knowledge of how to integrate technology into mathematics teaching; previous experience in using technology; pre-service education; professional development; availability of appropriate teaching materials; technical support; and support from colleagues and from school administrators.

In exploring factors influencing the integration of CAS into university mathematics, Lavicza (2007) suggests three interrelated clusters of factors: personal characteristics, external factors and various beliefs of mathematics lecturers regarding CAS and mathematics, and teaching/learning mathematics using CAS. The first cluster includes various personal and professional variables, including age, gender, mathematics research area, years of teaching mathematics, CAS use in research and computer literacy. The second cluster includes institutional and cultural contexts that may influence the working environments of lecturers. There are various levels within which external factors are explored: the course level (e.g. the nature of the taught courses); the departmental level (e.g. access to ICT resources, courses designed for which student cohort); the institution level (e.g. access, training, support); and the national level (e.g. quality and quantity of ICT infrastructure, education policy). The third cluster includes sub-clusters of lecturers' beliefs about mathematics, CAS, teaching/learning mathematics and teaching/learning mathematics using CAS.

As seen from the above reviews, the findings of previous studies suggest that access to resources, training, support and teachers' beliefs are the main factors that affect teachers' decisions to use technology in teaching. In what follows, I will briefly discuss the external factors such as access, training and support, followed by teachers' beliefs as a major internal factor.

2.4.1 External factors: access, training, and support

There is no doubt that the ability of teachers to access ICT resources is a necessary condition but may not be sufficient to use ICT in the teaching process. The NCTM stated the following as its position on the role of technology in the teaching and learning of mathematics: 'Technology is an essential tool for learning mathematics in the 21st century, and all schools must ensure that all their students have access to technology. Effective teachers maximize the potential of technology to develop students' understanding, stimulate their interest, and increase their proficiency in mathematics. When technology is used strategically, it can provide access to mathematics for all students' (NCTM 2008).

Mumtaz (2000), in her review of the literature, concludes that most researchers indicate that access to resources and the quality of software and hardware are key factors that influence the decisions by teachers to use ICT in classrooms. For example, in a case study exploring the factors that encourage or discourage the use of ICT by student teachers at a university-school teacher education program in England, Hammond *et al.* (2009) found that beyond student teachers' beliefs about the usefulness of ICT in their lessons as well as their beliefs that their students would welcome such use, the main factor was the access to ICT resources. The study revealed that in addition to good access to ICT resources at the university and schools, access to ICT at home was seen as essential to prepare earlier for the lesson. In addition, issues were raised regarding some difficulties in accessing schools' laptops to prepare for a lesson in advance, and in booking ICT rooms where every pupil could use a computer.

These findings reinforce what Jones (2004) asserts that access barriers cannot be removed simply by providing a sufficient amount of good quality equipment and software. There is also a need to deal with the other potential problems related to access, such as poor organization of the resources, which leads to the inability of teachers to gain access to these resources easily for the planning and preparation of lessons.

In reviewing mathematics education literature, Bergqvist, Holmquist, and Lingefjärd (2004) summarize the major reported reasons for not using ICT in teaching mathematical courses as follows: lack of resources, lack of appropriate programs, the belief that the use of software is not effective in teaching mathematics, the belief that there is no need to teach mathematics using ICT and the prevailing culture to avoid using ICT when teaching mathematical courses. Bergqvist *et al.* emphasize that nowadays, especially in the Nordic countries, the main factor that limits the use of technology in the teaching and learning of mathematics is not limited access to technology; instead it is the views and opinions of mathematical lecturers, though access may be a major obstacle in other parts of the world.

Training and support are factors that are directly related to access to resources. This is because teachers may have good access to ICT tools and resources at school and at home, but they may face difficulty in how to use these resources in teaching. It is important to provide teachers with training courses in skill acquisition as well as in how to use these tools to support effective teaching. In addition, for successful integration, teachers need adequate technical support to deal with the technical problems that could occur at any moment (Bingimlas 2009). These findings are consistent with Cox, Preston, and Cox (1999), who emphasize that training courses for teachers must focus on the technical aspects of ICT as well as on pedagogical practices in integrating ICT into the curriculum.

To investigate the factors that affect the integration in teacher preparation programs in Turkey, Goktas, Yildirim, and Yildirim (2009) collected questionnaire from deans, lecturers and prospective teachers in schools of teacher education, and conducted interviews with lecturers and prospective teachers. The results showed that the lack of access and training were the main barriers to ICT adaptation. In particular, there were complaints about the lack of in-service training for lecturers, the lack of an adequate number of computers and the lack of appropriate software.

Buteau *et al.* (2010), in their review of the literature, point to several technical issues identified by practitioners and researchers as being hindrances to technology integration into mathematics teaching at the university level. How to deal with technical problems (in case anything goes wrong) that may occur at any time during lectures was the most widely reported concern. Availability of computer labs came second among technical issues that were reported as being a major concern. The inadequacy of technical support came in third, followed by the unavailability of their chosen software within the IT facilities at the universities.

2.4.2 Internal factors: teachers' beliefs

In order to understand why some teachers use technology in their lessons and others do not, we need a better understanding of whether or not their beliefs about mathematics, about its learning and teaching, and about the role of technology, are influential in making such decisions.

The educational research community, as is the case in other communities, has been unable to come up with a specific working definition of beliefs (Pajares 1992). Of the many definitions of beliefs that are available in the literature, Cross (2009) defines beliefs as: 'embodied conscious and unconscious ideas and thoughts about oneself, the world, and one's position in it, developed through membership in various social groups; these ideas are considered by the individual to be true' (p. 326).The Oxford

English Dictionary defines belief as: 'an acceptance that something exists or is true, especially one without proof'.

Pajares (1992) states that 'The result is a view of belief that speaks to an individual's judgment of the truth or falsity of a proposition, a judgment that can only be inferred from a collective understanding of what human beings say, intend, and do' (p. 316). So, according to this definition, a reasonable conclusion about beliefs requires evaluation of what individuals say, what they do and what they intend to do. However, Pajares stresses that educational beliefs are multidimensional, and hence difficult to measure, but semi-beliefs such as 'self-efficacy' can be more easily operationalized and measured.

All teachers hold beliefs about their profession, their students, their subject matter and their role in the classroom. Hammond (2011) indicates that beliefs are a disputed concept and are challenging to identify. He stresses that behaviour cannot be predicted only by assessing beliefs. However, he argues that beliefs help in understanding the framework in which decisions about teaching, including the use of ICT, are made. Regarding the supposed association between teachers' beliefs and their classroom practices, Hammond emphasizes that the influence of beliefs on practice is not (and should not be) taken for granted. Goos (2013) points out that it is now generally recognized that the relationship between beliefs and practice is complex, with no clear linear relationship between the two. Cross (2009) reports other factors that may influence teachers' roles in the classroom. These factors can be internal, such as goals, emotions, teacher identity and teacher self-efficacy, or external such as institutional culture, curriculum demands, assessment requirements, and class sizes.

Ertmer (2005) points out that although teachers' beliefs have long been researched, relatively little research has been conducted on the relationships between teachers' pedagogical beliefs and their use of technology in teaching. Goos (2013) points out that studies investigating the relationship between teachers' beliefs and their classroom practices have yielded contradictory results, with some finding consistency between beliefs and practices and others identifying mismatches.

Beswick (2005) provides relationships between Ernest's (1989) categories of beliefs about the nature of mathematics, Ernest's beliefs about mathematics learning and Van Zoest *et al.*'s (1994) beliefs about mathematics teaching. These relationships are summarised in Table 6, in which beliefs in the same row are considered logically consistent, and those in the same column are considered as constituting a continuum.

Table 6: Relationships of teacher beliefs (Source: Beswick 2005, p. 40)

Beliefs about the nature of mathematics (Ernest 1989)	Beliefs about mathematics teaching (Van Zoest *et al.* 1994)	Beliefs about mathematics learning (Ernest 1989)
Instrumentalist (traditionalist)	Content focused with an emphasis on performance	Skill mastery, passive reception of knowledge
Platonist (formalist)	Content focused with an emphasis on understanding	Active construction of understanding
Problem solving (constructivist)	Learner focused	Autonomous exploration of own interests

As seen, although beliefs are generally regarded as important when studying the adoption of ICT by teachers, the relationship between beliefs and practices in the case of teachers is complex. Beliefs do influence teachers' practice but, at the same time, beliefs are influenced by teachers' instructional practice as well as by other internal and contextual factors.

2.5 Ways of Understanding the Take up of ICT

Looking back at the two ICMI studies on the use of technology in mathematics education, the evidence suggests that technology still plays a marginal role in the learning and teaching of mathematics.

Researchers have investigated the constraints on the take up of ICT in general, which can also be applied to mathematics classrooms. This has given rise to what might be understood as the factors approach, i.e. an approach which seeks to lists the factors which promote or constrain the use of ICT. However more subtle approaches are possible and the technology acceptance model, Valsiner's three zones theory and activity theory are three influential models that have been seen as assisting in studying the constraints and affordances of the use of ICT. These theories are described below.

2.5.1 Technology Acceptance Model

Many models have been developed by researchers from diverse disciplines to explain how individual users come to accept or reject the use of technology. One of the most influential and widely applied models is the technology acceptance model (TAM), proposed by Davis (1986) in the field of information systems.

TAM posits that perceived usefulness and perceived ease of use are the two primary predictors of an individual's intention to use a system, which in turn serves as a mediator for actual use of the system. Perceived usefulness is defined by Davis (1989) as: 'the degree to which a person believes that using a particular system would enhance his or her job performance' (p. 320), and perceived ease of use as: 'the degree to which a person believes that using a particular system would be free of effort' (p. 320). TAM also posits that perceived ease of use has a direct impact on perceived usefulness. Davis, Bagozzi, and Warshaw (1989) empirically validated TAM's ability to predict and explain an individual user's acceptance or rejection of word processing software. In a longitudinal study with 107 students majoring in business administration, intentions to use the software were measured at two points in time over 14 weeks. The study found that people's use of the system was predicted by their intention to use it and that perceived usefulness and perceived ease of use were strongly linked to intention.

TAM has been widely applied to explain and predict system usage behaviour across a wide range of computing technologies (e.g. spreadsheets, presentation software and e-mails) and covering a variety of users such as students, physicians, bank managers, Internet users and computer programmers (Chuttur 2009). In mathematics education, for example, Stols and Kriek (2011) used TAM to examine the influence of mathematics teachers' beliefs on their intended and actual usage of dynamic geometric software such as GeoGebra, Cabri 3D and Geometer's Sketchpad in their teaching. The findings indicated that perceived usefulness, in addition to teachers' technological proficiency, was the most significant factor of teachers' intended and actual use of software.

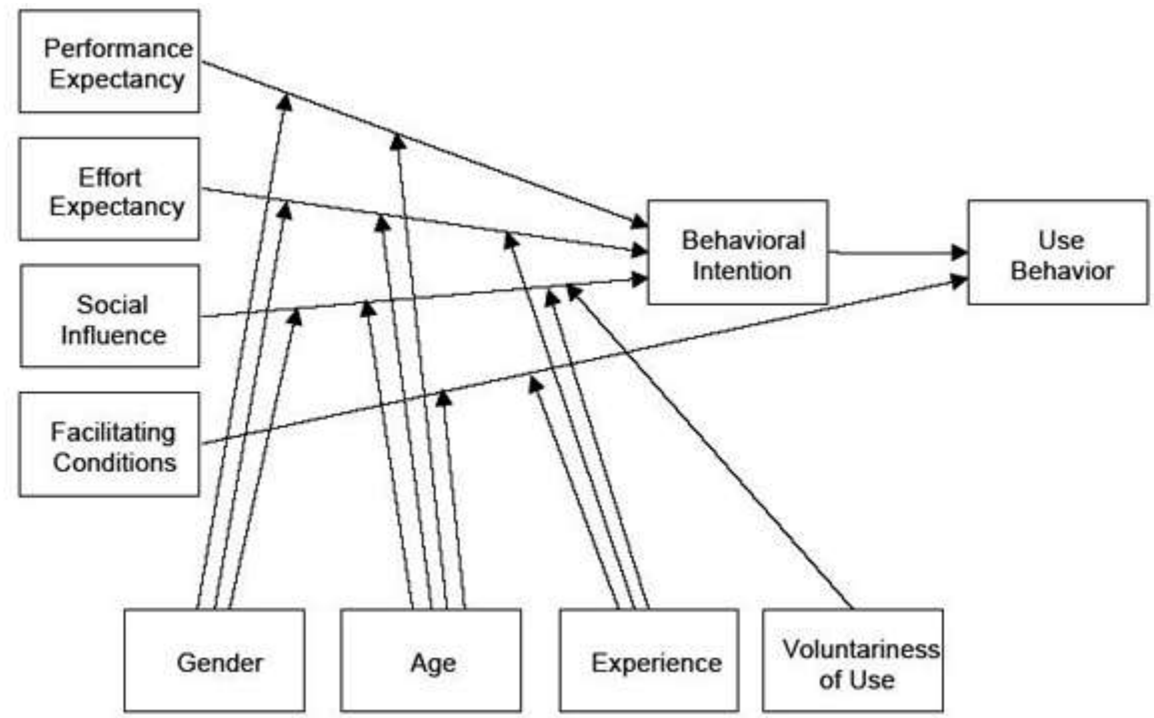
The unified theory of acceptance and use of technology (UTAUT) was an extension of TAM developed by Venkatesh *et al.* (2003). This was a condensation of 32 constructs from 8 models that earlier research had employed to explain information system usage behaviour. These were: the theory of reasoned action (TRA); TAM; the motivational model (MM); the theory of planned behaviour (TPB); the combined theory of planned behaviour/technology acceptance model (C-TPB/TAM); the model of PC utilization (MPCU); the innovation diffusion theory (IDT); and the social cognitive theory (SCT). UTAUT postulated that performance expectancy, effort expectancy, social influence and facilitating conditions are the key constructs that affect users' intentions to use a system and subsequent usage behaviour. Gender, age, experience and voluntariness of use are posited to mediate the effect of the four key constructs on the intention and actual use of a system (Venkatesh *et al.* 2003). The definitions of UTAUT's four key constructs with their root constructs from the eight models are summarized in Table 7.

Table 7: Definitions of UTAUT's four key constructs with their root constructs (Venkatesh et al. 2003)

Construct	Definition	Root constructs
Performance expectancy	'The degree to which an individual believes that using the system will help him or her to attain gains in job performance' (Venkatesh *et al.* 2003, p. 447)	Perceived usefulness (TAM/TAM2 and C-TAM-TPB) Extrinsic motivation (MM) Job-fit (MPCU) Relative advantage (IDT) Outcome expectations (SCT)
Effort expectancy	'The degree of ease associated with the use of the system' (Venkatesh *et al.* 2003, p. 450)	Perceived ease of use (TAM/TAM2) Complexity (MPCU) Ease of use (IDT)
Social influence	'The degree to which an individual perceives that important others believe he or she should use the new system' (Venkatesh *et al.* 2003, p. 451)	Subject norm (TRA, TAM2, TPB/DTPB, and C-TAM-TPB) Social factors (MPCU) Image (IDT)
Facilitating conditions	'The degree to which an individual believes that an organizational and technical infrastructure exists to support use of the system' (Venkatesh *et al.* 2003, p. 453)	Perceived behavioural control (TPBI DTPB, C-TAM-TPB) Facilitating conditions (MPCU) Compatibility (IDT)

The UTAUT was empirically validated using data from four organizations for a period of six months with measurements at three different times. It was found that the performance expectancy construct was the strongest predictor of intention and usage and remained as such at all measurement points in both voluntary and mandatory use. The effort expectancy construct was significant in the voluntary and mandatory contexts alike, but only during the initial period of use and it became less significant over periods of sustained usage. The social influence constructs remained not significant in the mandatory contexts, but became significant in the voluntary contexts. Facilitating conditions had a direct influence on intention and subsequent usage except for that explained by behavioural intentions alone.

Figure 5: The UTAUT (Source: Venkatesh et al. 2003)



Although TAM is a highly cited model, researchers have mixed views regarding its theoretical assumptions and practical effectiveness (Chuttur 2009). For example, Bagozzi (2007) raises concerns about critical gaps in the framework of TAM, pointing to the large gaps between intentions and behaviour, and between the perceived usefulness and perceived ease of use on the one hand, and intention on the other hand. Moreover, in the framework of TAM, there is an overdependence on a purely deterministic model in the sense that at each arrow in the model, the cause must lead to the effect. Furthermore, generally in TAM, emphasis is placed on an individual 'user' of a system and on the construct 'perceived usefulness'. There have been attempts to extend the model by bringing in more constructs to explain how an individual user 'perceives usefulness'. Social and cultural aspects should not be ignored because often decisions regarding technology acceptance or actual use of technology occur in a social context and with an understanding of if such usage fits with, or affects, other people or the requirements of a group.

As is evident from the above, TAM seems to be a deterministic model in which the decision (or intention) to use an IT system can be explained solely through beliefs (i.e. perceived usefulness and perceived ease of use). Beliefs are likely to be important factors in an individual's decision to the use an IT system, but they certainly should not be taken as fixed, nor should environmental, organizational and practical factors such as limited access to resources, lack of time, training or support be underplayed. Although TAM has been modified to include social factors, its focus still is on the individual rather than the system. What is needed is a model that takes into account social contexts, and purpose. Unlike in business, in teaching the terms ‘useful’ and ‘fit for purpose’ are unclear. For example, the use of software in examinations may be the most important factor in a teacher’s decision to use software in teaching. Education is a very different context from, say, business organizations, and goals in teaching are uncertain and messy, and a clear rationale is rarely apparent. Models developed for business and organizational work might not be applied so easily to a messy and very different context, as is the case in education, where uncertainty of goals is evident (and perhaps inevitable), and where interaction is occurring on multiple levels (between a human and other humans, between a human and a computer, and within one’s own ‘intra-psychological’’ system).

2.5.2 Valsiner’s Zone Theory

Based on the sociocultural perspective, which views learning as an interaction between teachers, students, mediating tools and elements of the physical and social environment, Goos and Bennison (2008) adapted Valsiner's (1997) three zones theory to explore the factors that affect the use of technology by mathematics teachers.

Valsiner developed his zones theory as a theory of human development in the field of developmental psychology, with particular attention to child development. According to Valsiner, this theory was an attempt to conceptualize three aspects of human development. The first aspect is the relation between developing persons and elements of their environment in the context of day-to-day actions. Second, there is the relation between the person's actions and reflection upon these actions. The third aspect includes the way in which the experiences of the developing person can transfer to the general life-course development.

Valziner used the three zones concept as an organizer of the process of human development in its dynamic flow, whether between a person and other elements in his or her surrounding environment, or within one's own thinking, feeling and acting. The theory takes into account both human agency and environmental structures. The theory includes three interdependent zones to account for the development of an individual in the context of his or her interaction with the physical environment and with other human beings in that environment: the zone of free movement (ZFM), the zone of promoted action (ZPA) and Vygotsky's zone of proximal development (ZPD).

Zone of free movement

The ZFM comprises 'what is available (in terms of areas of environment, objects in those areas, and ways of acting on these objects) to the child's acting in the particular environmental setting at a given time' (Valsiner, 1997, p. 317). Valsiner stresses that the structure of ZFM is primarily dynamic and the boundaries of ZFM are continuously being restructured (some elements may enter the ZFM and some may leave at any given time; some elements are well-defined whereas others may be ill-defined or undefined).

The ZFM is a social construct in the sense that it is created through social and cultural interaction between a developing person and others in his or her environment. The ZFM can either be set up by others, the individual himself or herself or through joint action, but are ultimately the ZFM is set up internally in the person's own personal thinking and feeling. The development of internal processes begins with the person acting within his or her environment, and progresses over time and as a result of the development towards internalization of the external experiences. The essential point stressed by Valsiner is that the ZFM can be applied beyond physical places, and may include thoughts and feelings, and that the ZFM is set up to organize person-environment relationships and to guide the development process (Valsiner, 1997).

Zone of promoted action

Valsiner defines the ZPA as: 'a set of activities, objects, and areas in the environment, in respect of which the person's actions are promoted' (p. 192). An important characteristic of the ZPA is its non-compulsory nature; a person is free to choose not to follow the ZPA developed by others, or he or she may choose to act with other elements within the ZFM.

Valsiner emphasizes that the ZFM and the ZPA together form a functional system that organizes an individual's development when interacting with elements of his or her surrounding environment; the ZFM keeps the person's acting or thinking within an acceptable boundary of actions (i.e. the ZFM limits the freedom of movement within specific areas of the environment), while the ZPA provides further suggestions for specific actions. This is why Valsiner stresses that instead of separating the ZFM and the ZPA from each other, it is more accurate to consider them as two parts that make up a whole: the ZFM/ZPA system. The ZPA may include subzones of ZFM, but may also include areas (at a particular point in time) outside the boundaries of ZFM.

The ZFM/ZPA system is not yet sufficient to explain the progress of an individual's development. This is because the ZFM/ZPA system has been implemented in ways that do not necessarily take into account the boundaries of the individual's capabilities and what is possible to be achieved at a certain point in time on the basis of a person's history of development. This is why there is a need to introduce a third zone that determines when the ZFM/ZPA system can meet its expected functions. This is the ZPD, which will be discussed below.

Zone of proximal development

Vygotsky's ZPD was re-constructed by Valsiner (1997) to make it subservient to the ZFM/ZPA system. Thus, it is described as: 'the set of possible next states of the developing system's relationship with the environment, given the current state of the ZFM/ZPA complex and the system' (p. 200). As noted above, the ZPD has a decisive role to play in personal development because one of the most important principles in successful implementation of the ZFM/ZPA system (or any other system) is mapping out what is possible. In the terminology of this theoretical framework, the whole system of ZFM/ZPA should fit ZPD at any given time. For instance, when teaching a student a certain skill, if the ZPA is set up in ways that do not intersect with the student's ZPD (outside ZPD at this point in time), then any effort to promote that skill at that point in time will necessarily fail. On the other hand, when the range of the ZPA provided for the student matches the student's ZPD, the maximum possible effect can be accomplished. In other words, for development to be possible, the ZPA must be within the boundaries of an individual's capabilities (or readiness) for development (ZPD) and must promote actions that are allowed within a given ZFM.

It is important to note that this theory was originally designed in the field of early childhood development, but as pointed out by Valsiner, there is no reason why this theory would not be applicable in adult development. In fact, the theory was applied to interactions between teachers, students, technology and the teaching-learning environment (e.g. Galligan 2005; Goos and Bennison 2008).

Goos and Bennison (2008) applies the three zones theory to understand why some teachers embrace (or reject) innovative teaching approaches promoted by teacher educators. In their analysis, Goos and

Bennison define these zones from the perspective of the teacher as learner. The ZPD represents a set of possibilities for teacher development influenced by their knowledge and beliefs about mathematics and mathematics teaching and learning, and about the role of technology. The ZFM suggests which teaching actions are allowed by constraints within the school environment, such as teachers' perceptions of students' abilities, motivation, behaviour, access to resources and teaching materials, curriculum and assessment requirements, and organizational structures and cultures. The ZPA represents teaching approaches that might be promoted by pre-service teacher education programs, professional development activities and interaction with colleagues at school. Table 8 presents the elements of Valsiner's (1997) zones for the case of teachers' use of technology as reported by Goos and Bennison (2008).

Table 8: Factors affecting teachers' use of technology (Source: Goos and Bennison 2008, p.105)

Valsiner's zones	Elements of the zones
ZPD	Mathematical knowledge Pedagogical content knowledge Skill/experience in working with technology General pedagogical beliefs
ZFM	Students' perceived abilities, motivation, behaviour, socio-economic background Access to hardware, software, teaching materials Technical support Curriculum and assessment requirements Organizational structures and cultures
ZPA	Pre-service teacher education Professional development Interaction with teaching colleagues

While it may be that the concept of three zones is merely re-labelling what is already known, perhaps its most important value is that it genuinely reflects the dynamic, chaotic (non-linear) and constantly changing nature of humans' relations with objects in their environments. The concept of zones is useful for studies that start from the premise that human phenomena cannot be separated from their contexts. This is especially the case for phenomena that involve relationships between individuals and elements of their environments, which necessitate an investigation into each individual as well as the contexts (environments) in which such relationships occur.

The zone concept is also useful because it captures the fuzziness of human phenomena in which there is an interaction between people and elements in their environment. Valsiner (1997) stresses that human development can be both deterministic and non-deterministic at the same time. It is deterministic in the sense that it is always bounded by sets of constraints, whether external (physical) or internal (cognitive or emotional). These sets of constraint regulate the development in some general direction. However, within the general direction provided by the constraints, the exact future state of development cannot be predicted from some previous state, hence the development remains nondeterministic.

As Valsiner argues, the notion that human phenomena are always constrained is perhaps one of the most important notions in this theory. This is because constraints function to partition a field into specific areas of possibilities to regulate and control the movement of a developing person within a heterogeneous group of individuals. Constraints can be external, or can be internal within a person's intra-psychological system.

The three zones theory belongs to cultural-historical theoretical perspectives, which place a great emphasize on the contexts and history of human phenomena. Valsiner (1997) states: 'the person cannot function without an environment and the environment of the person would not be the same if the person was eliminated from it' (p. 25). Human development varies according to the different contexts and the historical time periods in which human phenomena occur. Understanding the various contexts and histories is a requirement to understand the different individuals within the context of development. As in the case for the three zones theory, the cultural-historical perspectives and the historical contributions of Vygotsky were the theoretical bases on which the activity theory was established, as will be explained in the next section.

2.5.3 Activity Theory

Based on Vygotsky's sociocultural tradition, activity theory is a descriptive tool rather than a predictive theory. Originated within Soviet psychology, developed by Leontiev (1978) and then modelled by Engestrom (1987), activity theory emphasizes the socio-cultural effects of human actions. The theory provides perspectives on human activity and a number of concepts to describe the activity (Nardi 1996; Amory 2010).

The unit of analysis in the activity theory is a triangle model known as the activity system: a group of people who share a common goal over time, as well as a wide range of tools, language and symbols that are used to work on an object and to accomplish that goal. As shown in Figure 6, the elements of the activity system include subject, object, tools, community, rules, and division of labour (Engesrom 1987). Table 9 presents these six elements and their definitions, as reported by Mwanza and Engestrom (2005).

Figure 6: Components of the activity system (Source: Engeström 1987)

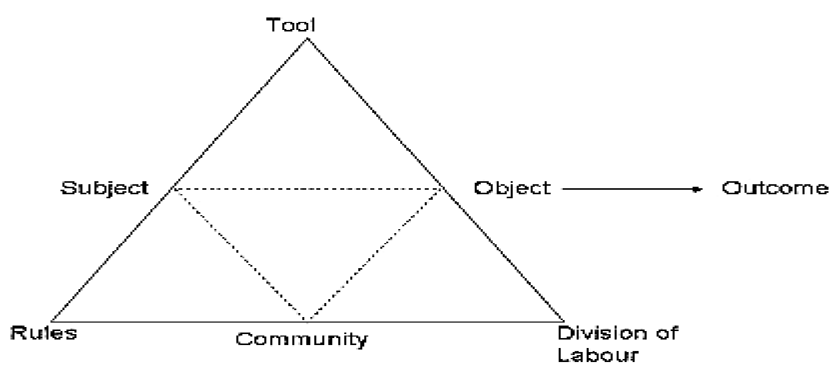


Table 9: Elements of the activity system (Source: Mwanza and Engestrom 2005, p.459).

Subject	Who is involved in carrying out the activity?
Object(ive)	Why is the activity taking place?
Tools	By what means are the subjects performing the activity?
Community	What is the environment in which the activity is carried out?
Rules	Are there any cultural norms, rules or regulations governing the performance of the activity?
Division of Labour	Who is responsible for what, when carrying out activity, and how are the roles organized?

Diagramming the elements of the activity system with their relationships is one of the methods used widely to help give a holistic view of the system including the 'context' of the community and its tools. This triangle representation of the activity system shown in Figure 6 is only for the sake of simplicity. This representation should not give the impression that the system is somewhat static or rigid, because in reality it is dynamic and constantly changing (Kutti 1996).

Nardi (1996) points out that activity theory proposes a strong notion of mediation and that all human activities are mediated by tools. A tool can be anything used in transforming an object into an outcome. Tools can be material (e.g. a textbook, a computer) or symbolic (e.g. language, signs). The elements at the base of the triangle (rules, community and division of labour) constitute the 'social basis' of the activity system. The social basis puts the activity in a broader social context, which helps in understanding the multilevel influences that shape the activity.

In activity theory, objects are transformed into outcomes not at once but through a process that typically consists of several phases. An activity also needs shorter-term steps during its implementation; an activity consists of coordinated actions or chains of actions, which in turn consist of operations. The three levels (activity, actions and operations) form what is known as an ‘activity hierarchy’, with activity at the apex. Action is a process undertaken with the overall motive of the activity in mind. Different actions may be carried out to accomplish the same goal. Actions are carried out in numbers of operations. Operations become routinized and ‘black boxed’ with practice (Nardi 1996).

Contradictions in activity systems

According to Kuutti (1996), activity systems are dynamic and constantly changing. Activities are influenced by external changes in the environment. The term ‘contradiction’ is used in activity theory to describe ‘a misfit within elements, between them, between different activities, or between different developmental phases of a single activity’ (p. 34). In activity theory, contradictions are not perceived as problems; on the contrary, they can be enablers for change. According to Engeström (1987), any activity system has four levels of contradictions that must be considered in the analysis of a working situation. Primary contradictions occur when a contradiction is found within a single node of an activity. Secondary contradictions occur between the constituent nodes. Tertiary contradictions arise between an existing activity and what is described as a more advanced form of that activity. And quaternary contradictions are contradictions between the central activity and the neighbouring activities.

Examples in which activity theory is used

Demiraslan and Usluel (2008) used activity theory, particularly the notion of contradictions between elements in an activity system, to examine the factors affecting the integration of ICT by teachers at the classroom level in Turkish schools. They conducted two case studies in two private primary schools. The participants were two teachers using ICT, ICT coordinators and students from each school. The methods employed for data collection were observations of lessons and interviews with two teachers (a science teacher from one school and a mathematics teacher from another school), students (focus group interviews) and ICT coordinators (one from each school). The elements of the activity system in this study are shown in Table 10.

Table 10: Elements of the activity system (Source: Demiraslan and Usluel 2008)

Subject	Teacher (teaching experience; teaching approach; the personal, administrational and instructional use of ICT; the place of ICT in daily life; the necessity of knowledge and skills related to ICT).
Object	The goals of using ICT in the teaching-learning process (knowledge and skills acquisition, and problem solving).
Tools	ICT and the tools other than ICT, methods that are used, problems that are encountered.
Rules	The evaluation criteria, expectations of the teacher, rules of the school.
Community	Students, teachers, school administration, ICT coordinator.
Division of Labour	The roles and responsibilities of students and teachers, cooperation among teachers, the support of administration.
Outcome	The reflection of the use of ICT in the teaching-learning process to the learning of students and instruction

The findings suggested that there were contradictions between different elements within the activity systems during the process of ICT integration. For example, there was a contradiction between the subjects and the division of labour in the sense that a teacher might have been willing to use ICT in the educational process, but did not find adequate support from the school administration. Also, the insufficiency of ICT resources resulted in a contradiction between a subject who was willing to use ICT and the lack of adequate tools. Moreover, the study found that the lack of adequate collaboration among teachers in the school regarding the use of ICT brought about a contradiction between object and division of labour. Furthermore, a contradiction between rules and object was suggested in the sense that the commitment to deliver the curriculum in time hindered greater involvement of ICT in teaching.

In another context, Blin and Munro (2008) adapted activity theory to study the factor limiting the full adoption of the VLE Moodle by the community of Dublin City University. They analysed an activity system for a unit of learning in Moodle (e.g. a module or sub-module, etc.). The elements of this activity system are summarized in Table 11.

Table11: Activity system for a unit of learning in VLE (Source: Blin and Munro 2008, p. 479)

Subject	Lecturers, support staff, individuals or teams
Object	Construction of a unit of learning
Tools	Preferred teaching approach; subject matter knowledge; existing learning objectives; technologies (production); technologies (delivery)
Rules	Academic structure and calendar; marks and standards; module descriptor
Community	Colleagues from DCU and elsewhere
Division of labour	Vertical and horizontal

The activity system was discussed at three levels: operations, actions and activity. At the level of operations, for example, a VLE allowed speed automation and substitution of human operations (e.g. automatic enrolment of students in a particular course, automatic correction and grading of tests, etc.). At the level of actions, the various components of the VLE enabled lecturers and designers to set up learning activities. This in turn enabled students to manipulate content, either independently or collaboratively (e.g. quizzes, wikis, glossaries, discussion forums, chat rooms, etc.) so that meaningful learning could occur.

At the activity level, the VLE can be the main enabler for an activity. A VLE provides a set of templates, guidelines, communication tools and databases that enable lecturers and designers to share learning objects and collaborate. A VLE can thus be regarded as a 'disruptive' technology, which can enable lecturers and designers to either do what they could not do before or improve what they were already doing.

Blin and Munro (2008) found that although the VLE was used widely by lecturers within the university, such use did not transform teaching practices. The main interaction with the VLE by most lecturers was for uploading content, and face-to-face delivery was replicated online.

As seen, both Valsiner's (1997) three zones theory and activity theory have been built on the cultural-historical perspective. Both theories study human development and both focus on individuals as well as collective dimensions. Both theories view development as dynamic and multileveled, and each of them emphasize interaction in social contexts. Both theories focus on the notion of constraints (the zones theory uses the term 'ZFM', while in activity theory 'rules' and 'division of labour' represent the constraints). Activity theory emphasizes that interaction is mediated between individuals and elements of the environment, whereas the three zones theory focuses on the concepts of zones as a genuine depiction of such interaction at any given time. Finally, the zones theory puts more emphasis on the issue of agency, while human agency is underplayed in activity theory.

2.6 Reflection on the literature review

As we have seen, this has been an eclectic review of the literature on the use of ICT in mathematics education. In the review, five key sections were presented. First, I focussed on philosophical views about the nature of mathematics and ways of looking at the subject. I then outlined the basic concepts of behaviourism, cognitivism and constructivism as three major theories of learning, and discussed their implications for teaching and learning. In the second part of the review, I gave an overview of current research regarding the use of ICT in mathematics education. In particular, I focussed on the findings of studies and reports by ICMI and CERME and on the remaining key challenges and theoretical gaps regarding the relationship between the learning (and teaching) of mathematics and the use of technology. In particular, instrumental genesis was found to be a promising theoretical framework for explaining the complex relationship between the use of software and the learning and teaching of mathematics, specifically addressing how a piece of technology emerges from being a mere artefact (e.g. a tool for quick computation) to an instrument for students' learning. In the third part of the review, I discussed the influence of mathematical software on the curriculum, as well as the learning and teaching of mathematics. Fourth, I discussed the factors influencing the take up of ICT and barriers to technology integration in education. Two sets of factors were discussed in more detail: The first included the major external factors, while the second set included teachers' beliefs as an important internal factor. In the last part of the review, I discussed three different theorisations of the take up of ICT, namely the technology acceptance model, Valsiner's three zones theory and activity theory.

Many of the sources cited and the topics covered in the review were particularly important in the methodological and analytical stages of this study. They directed my attention to the factors seen as important in the take up of ICT. These can be summarised as follows:

- Access: quantity (availability of hardware and software) and ease of access (e.g. pp. 40, 41, 63-64, 67-69, 80);
- Training and support: relevant training and on-site support (e.g. pp. 42, 55, 59, 66, 68-69, 85);
- Perceptions of software: benefits such as quick calculation, multiple representation and visualisation, and concerns such as overreliance on software and the inability to decide when and how to integrate software into teaching (e.g. pp. 47-53);
- Curriculum: what is covered and whether the use of software is assessed (e.g. pp. 40, 57-61, 63-64, 70, 80, 86);

- Competence: knowledge of how to use software in teaching and competence in using it (e.g. pp. 44, 52, 64, 66);
- Confidence (pp. 63, 64);
- Wider environment (e.g. pp. 66, 70, 73, 74, 80); and
- Beliefs: the nature of mathematics, as well as learner-centred versus teacher-centred teaching (e.g. pp. 32-33, 35-38, 63, 66, 69-71).

These factors work in two ways: Their presence encourages ICT use (e.g. easy access, pedagogical support, relevant training), while their absence discourages use of ICT (unreliable access, traditional assessment, low sense of self-efficacy).

These themes provide the framework for the rest of the thesis, and the chapter on methodology shows how they are employed in the survey design (pp. 120-121) and later in the analysis of the data (pp. 145, 146).

Regarding the wider literature and how it affected the nature and scope of my research, an obvious point to make is that this research could not cover or contribute to all of the topics reviewed. However, the topics were all important in 'staking out' the field of teacher take up of ICT, even if some were tangential to the research questions and some disappeared from view. For example, although my later study may seem merely to touch upon the nature of mathematics, the discussion is important both for me and the reader in that it draws attention to the fact that mathematics is not a 'thing', but rather a socially constructed field of inquiry. As such, different branches of mathematics may require or be associated with different institutional practices or traditions. Another topic covered in the review was theories of learning. This may seem only superficially relevant to the progressing study; however, looking at learning theories led me to ask how mathematics lecturers considered the subject to be best learned or taught and how ICT may be enlisted, or not, in the preferred teaching styles.

A further issue discussed in the review that later became tangential was instrumental genesis as a theoretical framework. While acknowledging the importance of instrumental genesis in examining the complex relationship between the use of software and the learning and teaching of mathematics, it was not possible in this study – both methodologically and practically – to study the 'process of emergence' from artefact to instrument. This would have required employing a more ideographic and observational research design involving three (irreducible) components, namely an artefact (the software), a task (e.g. finding the roots of an equation) and a subject (a lecturer who guides students as they develop a 'mental' scheme of using the artefact to solve the task). In the present study, which is primarily exploratory and largely based on survey data, I could not find an 'outlier' who was willing to be enlisted in the kind of in-depth study through which instrumental genesis could be explored. Nonetheless, instrumental genesis informed my interest in the 'how' part of integrating software into teaching, learning and assessing mathematics, and it was a topic I needed to raise.

Some issues were more tangential than others. For example, Tall's (2004) work on the three worlds of mathematics provides a useful way to classify mathematics in terms of the languages, objects, representations and methods of proof used. ICT can link these three worlds with one another. However, I was unable to develop this theme further. Laurillard's conversational model, besides being an influential model in higher education, shows a dialogue occurring at two levels. This provides an angle on the relationship between theoretical and practical mathematics, but again, it is one I was unable to develop further.

In the course of reviewing the literature, I became focussed on teacher take up as the field of study, because the literature (e.g. ICMI's reports) tells us that non-use of software is a critical issue. If we do not demystify (both theoretically and empirically) why take up is so problematic, then the use of mathematical software is doomed to continue to be patchy.

In terms of the take up of ICT, I could have explored a theoretical framework in advance, but chose not to do so because the factors' approach seemed comprehensive and explanatory. In any case, without my own data, I concluded that there was no reason to prefer activity theory, say, over TAM or Valsiner's zone theory. I initially wanted to know what enabled and constrained the use of ICT, and identifying factors would help me to explain the take up and to address what was going on and why. I thought (and still think) that using such modelling would be useful in theoretical and practical ways. Moreover, by taking the 'factors approach', I judged that I would be able to compare the findings of this 'never before studied' context with other findings from different contexts.

While modelling of factors turned out to be useful, I also became more aware of its limits once I had greater opportunity to reflect on my data and findings. In particular, I considered that there was a wider problem of agency, and lecturers' ability to exercise it, which was not covered well in the factors' approach. Chapter 6 sets out why I used Valziner's zone perspective, but I could not predict this in advance of data analysis.

My research agenda became focussed on lecturers' take up of mathematical software and my research questions narrowed to how and why (or why not) lecturers use (or do not use) mathematical software in their teaching. Further questions then suggested themselves. For example, my first question concerned the 'how' part: 'How, and to what extent, do lecturers use software in their teaching?' The second question settled on understanding the contexts or the environments in which those lecturers are working. The third concerned the subset of mathematics lecturers who use software more frequently in their teaching. This question emerged more strongly during the writing-up stage of the thesis, as it became apparent that identification with branches of mathematics was key in explaining the high (or low) use of software in teaching. The research questions are set out in full in the following chapter, which begins with a more general discussion of the research methodology.

Chapter 3 Research Methodology

3.1 Introduction

This chapter discusses the methodology of this research. First, research paradigms, epistemology and ontology, and methodology are discussed. In particular, two research paradigms, namely positivism and interpretivism, with their underlying ontological, epistemological and methodological assumptions, are discussed. I then discuss the reasons why this research subscribes to the post-positivist paradigm. After that, quantitative, qualitative and mixed-methods methodological approaches are discussed. I then turn to discussing the overall design of this research, which is a concurrent mixed methods two-strand design using Teddlie and Tashakkori's (2006) classification of different designs of mixed-methods research . The qualitative phase (the semi-structured interviews) and the quantitative phase (the questionnaire) of this research are then discussed. Finally, the measures to ensure the trustworthiness of this research, and ethical issues, are discussed.

3.2 Research paradigms

Researchers differ in the ways in which they seek to gain knowledge about a phenomenon they wish to describe. Ontology, epistemology, methodology and methods represent the four methodological levels at which the researcher needs to operate for knowledge acquisition. They affect every stage of the research, from determining the objectives of the research to reporting the findings (Scott and Morrison 2007). These four levels are represented in the arrow diagram shown in Figure 7.

Figure 7: Methodological levels (Source: Scott and Morrison 2007)

Ontology → Epistemology → Methodology → Methods

Researchers need to operate on two interlinked levels: a philosophical level (ontology and epistemology) and a methodological level (methodology and methods). The arrows in Figure 7 indicate that there are some philosophical questions about the nature of the reality and how one can know this reality, which ought to be addressed prior to making decision as to which strategies and methods should be employed. It is likely that if different decisions are made at the philosophical or beliefs level then this might lead to different decisions being made at the methodological or practical level. Researchers who want to conduct 'good' research need to understand the philosophical underpinnings that inform their choice of methodology and methods (Guba and Lincoln 1994).

At the philosophical level, epistemology, or a theory of knowledge, is influenced by ontology, or a theory of reality. Ontology deals with one's perspectives of the nature of the reality, whereas epistemology deals with one's perspectives on how we come to know this reality. Different researchers may have different assumptions of reality and knowledge, which underpin their research practices. This can be reflected in the methodology and methods they employ to address their research objectives (Guba and Lincoln 1994; Grix 2002; Scott and Morrison 2007).

Methodology, in research contexts, refers to the theory of how and why a researcher seeks to gain or construct knowledge about a particular phenomenon. The methodology of a research study provides a rationale for using a specific strategy and methods to achieve the research objectives. Methodology is closely related to epistemology: the latter involves the philosophy and the former involves the practice of how one comes to know the reality he or she wishes to know (Scott and Morrison 2007). Ethnography, survey and grounded theory are examples of research strategies. Methods are the techniques that researchers utilize in their quest to answer the research questions. As stated in Bryman

(2008), methods might be instruments of data collection such as questionnaires, interviews or observation, and they also might be the tools used for analysing data. These tools might be statistical analysis or analytical techniques, such as extracting themes from unstructured data. It is important to stress that the methods undertaken in a study are only one component of the methodology. Data can be either qualitative or quantitative.

The term ‘paradigm’ has become commonly used in the field of social science since first being used by Thomas Kuhn when he put forward the concept of ‘scientific revolutions’ in his influential book ‘The Structure of Scientific Revolutions (1962)’. Kuhn defines the term ‘paradigm’ in the preface of his book as ‘universally recognized scientific achievements that for a time provide model problems and solutions to a community of practitioners’ (page viii). In other words, a paradigm in Kuhn’s view can be characterized as the framework that dominates a particular discipline at any given time. This framework contains all the commonly accepted theories, techniques and laws shared by a community. Perhaps one of the most ground-breaking ideas of Kuhn’s work is his view on ‘incommensurability’. Kuhn argues that new and old paradigms are not compatible with one another, and that the transformation to a new paradigm occurs in a revolutionary and not cumulative linear manner, as was a common belief at the time. This transformational change (i.e. the paradigm shift) leads to the emergence of a new paradigm completely replacing the paradigm that was dominant before.

Social research has ‘borrowed’ the word paradigm and redefined it in ways that do not necessarily adhere to Kuhn’s use of the word (e.g. Bryman 2008; Creswell 2009). For example, Guba and Lincoln (1994) view the paradigm as ‘a worldview that defines, for its holder, the nature of the ‘world’ the individual's place in it, and the range of possible relationships to that world and its parts’ (p. 107). In the current research, I employed Creswell's (2009) definition of the paradigm. Creswell views paradigms as systems of beliefs, or world view, based on ontological and epistemological assumptions that guide research. I see a paradigm as having the same meaning as terms such as 'school of thought', 'doctrine' or 'perspective' about reality and knowledge of an educational phenomenon. A paradigm includes the philosophical positions of the researcher (ontology and epistemology) along with subsequent methodologies that govern the thinking and practices of the researcher during all stages of the research.

Each paradigm has its own ontology and epistemology. Each paradigm offers answers to fundamental questions such as: is there an absolute and objective truth about what we are to find out? Or are there multiple truths that are changeable according to different contexts and times? Can such reality be studied independently of the researcher? Can social reality be studied using the same principles employed by the natural sciences? Is knowledge discovered or constructed? Can knowledge be acquired (constructed) independently (or dependently) of the social and historical contexts in which it exists? Further, within each paradigm, ontological and epistemological assumptions have an impact on the methodology chosen by the researcher, which in turn influence the choice of methods to achieve the desired objectives of the research. To obtain or build knowledge about a particular phenomenon, some researchers prefer to be distant from the respondents who are being studied (e.g. positivists), while others prefer to immerse themselves in what they are studying (e.g. interpretivists).

Although there are many different paradigms, involving disputed philosophical assumptions, it is possible to represent social research on a continuum ranging from 'objectivism' at one extreme to 'subjectivism' at the other (Huglin 2003) (see Figure 8). For accessibility, I will use positivism as a term to capture one approach to research and interpretivism as another. But as Ryan (2006) asserts, setting up positivism and interpretivism as if they were opposite to each other is an oversimplification that does not adequately reflect the chaotic and messy nature of how research is conducted. Understanding beliefs along a continuum provides more flexibility for researchers so that they are not 'forced' to place themselves in a single camp and have to choose the lesser of two evils.

Figure 8: A continuum of positivism and interpretivism

Nonetheless, it is useful at this point to consider positivism and interpretivism in more depth. Before doing this, it is necessary to note that there are different perspectives on these concepts as well as many variations on each (e.g. empiricism, logical positivism, classical positivism, post-positivism, moderate constructivism, radical constructivism, social constructivism, evolutionary constructivism and postmodern constructivism) (Crotty 1998; Murphy 1997). What is important is that positivism and interpretivism offer different perspectives about the reality of phenomena that we wish to describe and about how we come to know such reality.

What follows is a brief discussion of positivism and interpretivism, followed by a brief discussion of post-positivism, an approach to which this research subscribes. I shall discuss these concepts, focusing primarily on the ontological and epistemological assumptions as well as the subsequent methodologies and methods of data collection of each.

Positivism

The central tenet of the positivist paradigm is that the methods of the natural sciences can be applied to the social world. 'Scientific method' is defined by the Oxford English Dictionary as: 'a method of procedure that has characterized natural science since the 17th century, consisting in systematic observation, measurement, and experiment, and the formulation, testing, and modification of hypotheses '. According to Bryman and Bell (2007), positivism entails four main principles:

1. True knowledge about a phenomenon can only be gained from the senses (the principle of phenomenalism).
2. Theory is used to develop hypotheses that can be tested using empirical data that allow confirmation or dis-conformation of the original hypotheses (the principle of deductivism).
3. Knowledge can be acquired through the accumulation of facts (observation) about phenomena that provide the basis for true laws (the principle of inductivism).
4. Research can and should be conducted in an objective way (i.e. value-free research).

Bryman and Bell stress that despite the fact that research that follows the positivist school of thought tends to use deductive research strategies, there are some circumstances where inductive methodology is appropriate in positivism-based research. However, positivists generally believe that there is a standard set of procedures (mainly based on the deductive model of inquiry) for investigating phenomena and presenting findings (Ryan 2006).

The ontology of the positivist paradigm is that objects in the social world have an objective reality independent of the researcher's personal conception of them (Scott and Morrison 2007; Guba and Lincoln 1994). Within this paradigm, knowledge is regarded as separate from the person who seeks to acquire it. It is regarded as being something discovered, not constructed by social actors or by the researcher (Ryan 2006). The positivist philosophy posits that the aim of research is to 'mirror' reality through objective (value-free) scientific investigation (Järvensivua and Törnroosb 2010).

Researchers within the positivist paradigm approach knowledge discovery from an etic (outsider's) perspective. This means that the researcher remains an 'outsider', detached from the respondents emotionally and physically in order to objectively measure reality (Harvard University 2008). As stated in Scotland (2012), positivists imagine they can go out into the world without bias, seeking to discover the absolute knowledge of an objective reality. Researcher and respondents remain two separate entities.

Meaning exists only in the objects, regardless of what the researcher believes or feels about it, and the researcher's goal is to get to this meaning. Thus, phenomena have an independent existence that can be discovered through research. Researchers who believe in the positivist philosophy believe that the goal of knowledge is to observe, measure and describe the phenomena being researched. Positivists view acquiring knowledge of anything beyond that as not being counted as 'true' knowledge (Grix 2010; Trochim 2006).

One of the hallmarks of the natural sciences model of inquiry is that it employs a 'nomothetic' rather than 'idiographic' research methodology. As mentioned in McLeod (2007), those who adopt nomothetic methodology are mainly concerned with studying what one shares with others. As the 'nomos' in 'nomothetic' means 'law' in Greek, the nomothetic methodology is designed to discover general laws (e.g. correlations, generalizations, etc.). Therefore, positivists who employ experiments, correlations and other quantitative methods use nomothetic methodology.

Positivists tend to use quantitative methods with a focus on hypothesis testing. As Scott and Morrison (2007) put it: 'Variable analysis is underpinned by an empiricist view of reality, which gives a privileged status to sense data and marginalizes the need for depth ontology' (p. 195). Positivists mainly utilize top-down ('deductive') methods of inquiry. They use statistical analysis and seek to generalize their findings.

Within the quantitative approach, there are experimental, quasi-experimental and non-experimental studies. Questionnaires with closed-ended questions are commonly used as data collection methods by positivists. As stated in Mack (2010), the purpose of research within the positivist paradigm is to prove or disprove a hypothesis. Researchers seek predictions and generalizations, and therefore, the methods used often generate quantitative data. Examples of these methods include standardized tests and closed-ended questionnaires. Analysis involves descriptive and inferential statistics. Inferential statistics allow the sample results to be generalized to entire populations (Scotland 2012).

The positivist paradigm provides a theoretical basis for quantitative methodology. Those who subscribe to the positivist paradigm tend to conduct quantitative, not qualitative, research. Positivist researchers seek knowledge by collecting numerical data on observable behaviours of samples, and then the data are subjected to statistical analyses (Huglin 2003). Research is deemed of good quality if researchers are measuring what they intend to measure (internal validity), and if different researchers can collect the same data in the same way and reach the same conclusions (replicable and reliable). Good research generalizes its findings to the entire population (external validity) (Scotland 2012).

There has been widespread criticism of the positivist philosophy for applying scientific methods to research in human affairs. Human beings have agency and invest the world with meaning. Positivism struggles to engage with how people live, how they see the world and how they change it. Ryan (2006) stresses that there has been an overall criticism of positivism regarding the over-simplification (reductionism) of human experience. Critics argue that the 'cause and effect' relationships that can be established when studying natural phenomena cannot be identified in the social world. An example of positivist thinking that has been criticized (e.g. Trochim 2006) is B.F. Skinner's theory of behaviourism. Skinner argued that psychology needed to concentrate only on reinforcing behaviours in order to predict how people will behave. This theory has attracted a great deal of criticism because it over-simplifies human affairs into observable behaviours, disregarding feelings, thoughts and other internal human states.

Interpretivism

The basic tenet of interpretivism is that social reality is constructed by human beings and should not be studied using the same principles employed by the natural sciences. Interpretivists suggest that social reality is subjective (we all have our perspectives on the world) and socially constructed (we can reach agreements about the world even if these agreements may serve the interests of some people more than others).

Constructivism has had a heavy influence on the interpretive approach to research, and has in turn been heavily influenced by hermeneutics and phenomenology. Hermeneutics, in its broadest definition, is the theory of interpretation. More specifically, it means the study of the interpretation of written texts (e.g. religious texts). According to Scott and Morrison (2007), research in the social world can be characterized as a double hermeneutic. This is because researchers are interpreting the interpretations made by the participants in the research. Another strong influence on the interpretive approach comes from phenomenologists, who advocate 'understanding social phenomenon from the actors' own perspectives and describing the world as experienced by the subjects, with the assumption that the important reality is what people perceive it to be' (Kvale and Brinkmann 2009, p. 26). Therefore, the ontological position of interpretivism is that social reality is socially constructed by people who have different interpretations of social phenomena. Reality is what the local actors subjectively interpret it to be, and the interpretation of 'realities' will differ from context to context and from time to time. The researcher within this paradigm seeks to construct knowledge through these multiple perspectives of reality (Guba and Lincoln 1994; Scott and Morrison 2007; Järvensivua and Törnroosb 2010).

The epistemological position of the interpretivists researchers involves immersing themselves in what they are studying or researching (Bryman and Bell 2007). Interpretivists believe that knowledge construction is a subjective process resulting from interaction between the researcher and the researched, and that reality is co-constructed as a result of such an interaction (Guba and Lincoln 1994). Mack (2010) points out that interpretivism's main tenet is that research can never be objectively observed from the outside; rather, it must be observed from inside through the direct experience of the people. Therefore, an emic (insider's) approach to knowledge construction is used (Harvard University 2008).

Interpretivists tend to use 'ideographic' rather than 'nomothetic' methodologies. As mentioned in McLeod (2007), the term 'idiographic' comes from the Greek word 'idios' meaning 'own' or 'private'. Researchers who use ideographic methodologies are generally interested in studying individual cases rather than seeking to establish relationships or to generalize to larger populations. Ideographic methodologies rely on specific and contextual understanding of social reality. Case studies, unstructured interviews and other qualitative research strategies and methods are idiographic in nature.

Interpretivists generally use a bottom-up approach (inductive) starting from the perspectives of the participants. As stated in Huglin (2003), those who lean toward interpretivism are more likely to conduct qualitative research. They develop knowledge by collecting primarily verbal data through the intensive study of cases and then subjecting these data to analytic induction. The main methods undertaken within the qualitative paradigm include: focus groups, in-depth interviews and unstructured observations. Examples of different methodologies within the qualitative research include: case studies, phenomenology, hermeneutics and ethnographies.

As discussed by Onwuegbuzie, Johnson, and Collins (2009), descriptive statistics can be used to enhance the qualitative researcher's quest for concrete descriptions of social reality, and help address issues such as trustworthiness, dependability and authenticity. However, as stated by Scotland (2012), 'good' interpretivist research provides rich evidence and offers credible and justified accounts (internal validity/credibility), it can be used by someone in another case (external validity/transferability) and the research process and findings can be replicated (reliability/dependability).

One limitation of interpretivist research is that its findings cannot be generalized to the wider population. Therefore, many positivists question the overall benefit of interpretivist research. Another criticism of interpretivism is that the ontological assumption is subjective rather than objective (Mack 2010). Further, as discussed by Onwuegbuzie *et al.* (2009), interpretivists often claim that multiple, but equally valid, accounts of truths can exist. Thus, it is somewhat contradictory that those who subscribe to such a philosophy do not view the use of quantitative methods as representing one valid account of the truth.

Going beyond dichotomies

As pointed out in Corman and Poole (2000), post-positivism is a paradigm that derives its principles from both the positivist and interpretivists traditions. In the paradigm's continuum, post-positivism can be positioned at some point between positivism and interpretivism. Post-positivists believe that although there is a reality that can be studied independently of our conception of it, they assert that all observation is fallible and that every theory can be modified. They believe that the truth can be multi-layered, and it is verifiable and subject to change (Hartas 2010). They maintain that there are limits to how fully we can understand reality; truth can only be partially and probabilistically apprehended (it is possible to approximate, but never fully know) (Guba and Lincoln 1994; Scott and Morrison 2007).

Post-positivists believe that, as a result of their experiences, culture and worldviews, people are often biased, or at least partially biased, in their perception of reality. Their perception and observation of the world is fallible; post-positivists emphasize that we can only approximate the truth but can never comprehend it perfectly. They maintain that objectivity can be approximated by triangulating across these multiple (fallible) perspectives. The goal of the research is to get as close as possible to understanding reality (Onwuegbuzie *et al.* 2009). A philosophical support comes from Popper in his famous book, ‘The Logic of Scientific Discovery’ (1959). Popper posits that there is no such thing as an absolute truth—a view that might question the fundamental features of positivism (e.g. prediction and generalization) when dealing with the social world. He argued that scientific theories cannot be confirmed but only falsified; hence, our knowledge of the world is fallible. Table 12 shows a comparison of ontological beliefs between positivism and post-positivism (Hartas 2010, p. 38).

Table 12: Different philosophical positions of positivism and post-positivism (Source: Hartas 2010, p. 38)

Positivism	Post-positivism
Objective observation	Observation is theory laden
Absolute truth	Observation being fallible and theory revisable
Objectivity as an individual endeavour	Objectivity is a collective enterprise
Language being neutral	Language being imbued with meaning, language as discourse
Reality as experienced	Reality as shaped by language and discourse

For post-positivists, knowledge acquisition occurs as a result of non-falsified hypotheses that can be regarded as 'probable' facts. As discussed by Trochim (2006), because all measurement is fallible and theory-laden, the post-positivists emphasize the importance of triangulation across multiple methods to try to get a better understanding of reality. Therefore, a mixed-methods approach to knowledge acquisition is probably appropriate within the post-positivism paradigm.

My position

After discussing different philosophical paradigms and the underpinning assumptions of each, two key points need to be made. The first point is that I would generally align myself with the post-positivist paradigm. I see that post-positivism is located in the middle ground between positivism and interpretivism. I am an interpretivist in the sense that I believe that each one of us constructs her or his own views, but I believe there is a material reality outside of my perception of it. I believe that social reality cannot be fully determined, yet it can be partially understood. I also believe that this reality is local, fluid and is shaped by social and cultural norms. I believe that meaningful reality is what local people perceive it to be. In this case, I believe in the use of quantitative methods to measure variables in social reality and study association, and at the same time I maintain the need to understand social phenomena from the local actors' points of view.

The second key point is that whatever position one holds on these key issues within ontology and epistemology, in practice, one's stance is mediated by the kinds of research questions one asks. In this study, I was asking questions influenced by both interpretivist and positivist traditions. RQ1 ('How, and to what extent, do lecturers use the software in the teaching of university-level mathematics courses?' and RQ3 ('Do particular individuals or groups of mathematics lecturers use software more than others?') lean more heavily towards the 'positivist' side of research. They suggest that there are behaviours which can be objectively reported; in my study, although this involved a fair degree of self-reporting, what is self-reported is subject to a credibility check and triangulation. RQ4 ('What encourages/motivates lecturers to use the software in the teaching of university-level mathematics courses?') and RQ5 ('What discourages/constrains lecturers from using the software in the teaching of university-level mathematics courses?') belong to the more 'interpretivist' tradition investigating what people think, feel and experience in relation to a particular set of circumstances. RQ2, which is about the context in which lecturers use ICT in the teaching of university-level mathematics, covers both interpretivist and positivist traditions. The nature of the questions I am asking led me to a genuine mixed-methods approach in which my focus of attention shifted back and forth from examining a 'social reality' to examining how 'actors' interpret that reality. Other approaches were of course possible; for instance, an ethnographic study could have been used to explore more deeply the experiences of the lecturers. However, this would have involved asking different questions (e.g. 'What do actors think is happening as technology is introduced?') and methods (e.g. extensive participant observation fieldwork). As seen, I chose not to ask these questions or adopt this ethnographic approach, chiefly because I could not be confident of gaining the necessary access, but also because I thought the questions I was asking about the extent of ICT use and the more general scope of my inquiry were of more immediate concern.

To sum up, from the above discussion we have seen that there are different paradigms in the social sciences that share the common goal of gaining understanding and developing evidence when investigating social phenomena. These paradigms differ in terms of their underlying ontological, epistemological and methodological assumptions. We have discussed that positivists tend to use experimental and quantitative methods to test and verify hypotheses, whereas interpretivists generally use qualitative and naturalistic methods to inductively and holistically understand human experience within a specific context. This research takes a middle-ground position, assuming that both quantitative and qualitative methods are not incompatible and that combining them may lead to better understanding of the investigated phenomenon. In particular, this research subscribes to the post-positivist paradigm and uses both quantitative and qualitative methods. On the one hand, this research deals with variables within the context of complex, real-life social experiences; therefore, the use of a quantitative approach alone is insufficient. On the other hand, since this research seeks to establish relationships and associations between different measured variables across larger populations, the qualitative approach alone is not sufficient for this research.

3.3 Research methodology

Having discussed research paradigms, epistemology and ontology, I will now turn to methodology. As previously discussed, methodology refers to the strategy adopted for addressing research questions. Generally, there are three broad methodological approaches that might be employed by researchers: the quantitative approach, the qualitative approach and the mixed-methods approach. Within each approach, there exist strategies of inquiry that provide specific direction for procedures in a research design (e.g. experimental research, survey research, ethnography, case studies, action research), and methods to collect and analyse data (e.g. questionnaires, interviews, observation, focus groups) (Tashakkori and Teddlie 1998; Creswell 2009).

Quantitative approaches

Perhaps the broadest definition of quantitative research is that it denotes the empirical research in which the data are in the form of numbers (Punch 1998). From a philosophical perspective, quantitative approaches have been associated more with the positivist paradigm, which assumes that the natural science model of inquiry can be applied when investigating phenomena in the educational world (Scott and Morrison 2007). Creswell (1994) defines quantitative research as: 'an inquiry into a social or human problem, based on testing a theory composed of variables, measured with numbers, and analysed with statistical procedures, in order to determine whether the predictive generalizations of the theory hold true' (p. 2).

As Creswell's definition indicates, in the quantitative approach the main aims are to objectively measure the objects in the social world, test hypotheses and explain and predict human behaviour by using statistical analysis with large sample sizes. The focus in this approach is on measuring variables, establishing associations, testing relationships and studying causes and effects (Scott and Morrison 2007).

The most common strategies of inquiry in quantitative research are experimental, quasi-experimental or non-experimental studies (survey research). The commonly used measures and data collection methods include structured observation and questionnaire surveys with closed-ended questions. Deductive reasoning informed by statistical analysis is used to solve the research problem. Many studies are descriptive, or non-experimental, in nature. Surveys are often used to measure a concept with the goal to discover the frequency of a behaviour or test relationships and compare attitudes. Correlational studies (e.g. survey research) establish associations between concepts, but they do not imply cause and effect relationships (Punch 1998).

The strengths of the quantitative approach are: it is viewed as more scientific and objective; it can produce valid outcomes through reliable measurement (Hughes 2006); and its large-scale findings can be generalized. However, Scott and Morrison (2007) dispute the claim that quantitative approaches are totally objective. They stress that the researcher's values and influences cannot be totally eliminated. The researchers are subjectively involved in whether or not the chosen problem is worthy of investigation, in the framing of the questions, in the construction of the research instruments and, though perhaps less so, in the interpretation of the results. Hughes (2006) points out quantitative approaches' failure to take account of people's unique ability to interpret their experiences and construct their own meanings. Further, she stresses that due to the complexity of human experience, it is difficult to rule out or control all variables. Another criticism mentioned by Hughes is that the use of quantitative methods might lead to the assumption that facts are true and apply to all people all the time, ignoring the fact that people do not all respond in the same ways, as material objects in the natural and physical world do. One of the difficulties with this assumption is that the natural and physical sciences in general work with closed (consistent and predictable) systems, whereas the social world constitutes an open (inconsistent and unpredictable) system (Scott and Morrison 2007). Critics of the quantitative approach oppose the principle of treating people in open systems in the same way as in dealing with molecules and atoms in closed systems, notwithstanding the uniqueness of people from one another and the nature of their unpredictable behaviours and agencies.

Qualitative approaches

Broadly speaking, qualitative research has come to denote empirical research in which the data take the form of words, rather than numbers (Punch 1998). From a philosophical perspective, qualitative approaches are often assumed to be associated with the interpretivist paradigm, which assumes that the social world is fundamentally different from the world of physical sciences, and hence the research needs to focus upon seeing the world through the eyes of those being studied (Scott and Morrison 2007). The qualitative approach is defined by Creswell (1994) as: ‘an inquiry process of understanding a social or human problem, based on building a complex, holistic picture, formed with words, reporting detailed views of informants, and conducted in a natural setting’ (pp. 1–2).

The qualitative researchers’ main interest is in understanding the subjective realities from the research participants’ own perspectives (Scott and Morrison 2007). They seek a more holistic understanding, rather than a detailed description of the investigated experience as it is lived by the research participants (Hughes 2006). They mainly use a naturalistic approach, aiming for a ‘rich and deep description of individuals, events and settings, in which few details are excluded, in order to ask ‘what is going on here?’ (Scott and Morrison 2007, p. 183). Qualitative researchers emphasize that the data do not exist in a vacuum, and they always insist that the data must be understood through their social and historical context. Therefore, they adapt an emic approach, immersing themselves in the investigated settings.

The qualitative researcher mainly adopts an inductive approach to knowledge construction. Often, the findings of qualitative research include themes and subthemes. Common strategies of inquiry that are associated with qualitative approaches include: case studies, action research and ethnographies. Among the commonly used qualitative data collection methods are focused group and un-structured interviews.

The strengths of the qualitative approach are that it gives a richer, fuller and deeper description of the studied phenomenon. As Hughes (2006) points out, the qualitative researcher is closely involved with the lived experience of the participants, enabling the researcher to obtain an insider’s view of the field. This in turn allows the researcher to uncover issues that may otherwise be missed. However, one major concern when it comes to qualitative research is the lack of objectivity and bias by the researcher (e.g. the issue of whether the researcher's presence has an impact on the conduct of the participants). Further, due to the subjective nature of qualitative research methods and the inability to separate the results from the contexts in which they originated, it is difficult to apply standardized methods to assess the validity of the results, or the reliability of the measurements.

One limitation concerning qualitative research that has triggered debates among educators (e.g. Guba and Lincoln 1985) is that qualitative inquiries are characterized as being local, unique and context-dependent; hence, they cannot be replicated or generalized to a wider context. Guba and Lincoln suggest the notion of transferability in qualitative research as an alternative to the generalizability of quantitative research.

Mixed-methods approaches

While the quantitative and qualitative approaches are the two traditional approaches to research, more and more researchers, especially in recent years, do not view them as mutually exclusive, and hence, they employ both of them in the same research, especially when neither of the two approaches alone could completely answer the research questions (Punch 1998). Generally, the advocates of using mixed-methods approaches do not deny the philosophical differences between the paradigms or the outstanding issues concerning the epistemological and ontological differences between the qualitative and quantitative approaches to research. Instead, they call for a rather pragmatic approach that advocates the use of all appropriate means available to achieve the objectives of the research (Bryman 2008).

As mentioned by Scott and Morrison (2007), there are several reasons for using the mixed-methods approach: 1) combining quantitative and qualitative research in one research enhances triangulation; 2) each one of the two methods can be used to complement or facilitate the other (e.g. the findings from one approach can be used to elaborate, illustrate and/or clarify the findings from the other); 3) employing quantitative approaches can overcome the generalizability issue in qualitative approaches to research; 4) combination yields a fuller picture of the investigated phenomenon; and 5) both outsider and insider perspectives can be facilitated when both approaches are employed within one research. While one advantage of mixed-methods research is that it enables researchers to simultaneously ask confirmatory and exploratory questions, and therefore verify and generate theory in the same study (Teddlie and Tashakkori 2006), conducting mixed-methods research requires more experiences and extra time and resources to combine both quantitative and qualitative data (Creswell and Plano Clark 2011).

While I recognize that none of the classifications of mixed-methods designs that have been presented in the literature (e.g. Tashakkori and Teddlie 1998, 2003; Teddlie and Tashakkori 2005; Creswell 1998) are fully comprehensive and cover all the designs that may exist, these classifications are nonetheless valuable in classifying most designs. One of these classifications of different designs of mixed-methods research is presented by Teddlie and Tashakkori (2006). This classification is called the 'methods-strands matrix' (see Table 13). This classification encompasses mono method designs (qualitative or quantitative), but also includes mixed-methods designs, especially four families of mixed methods designs: sequential, concurrent, conversion and fully integrated.

Table 13: The methods-strands matrix—A typology of research designs featuring mixed methods (Source: Teddlie and Tashakkori 2006, p. 15)

Design Type	Mono-Strand Designs	Multi-Strand Designs
Mono-Method Designs	Cell One Mono-method mono-strand designs: (1) Quantitative design (2) Qualitative design	Cell Two Mono-method multi strand designs: (1) Concurrent mono-method (2) Sequential mono-method
Mixed-Methods Design	Cell Three Quasi-mixed mono-strand designs Mono-strand conversion designs	Cell Four Mixed-methods multi-strand designs: (1) Concurrent mixed designs (2) Sequential mixed designs (3) Conversion mixed designs (4) Fully integrated designs

At the outset, any study involves three consecutive stages: the conceptualization stage (e.g. formulating research purposes and questions, reviewing previous literature), the experiential (methodological and analytical) stage (e.g. data gathering, data analysis) and the inferential stage (e.g. emerging theories, explanations, inferences). As shown in Table 13, two criteria are used to construct the matrix, namely: type of methods employed in the study (mono method or mixed methods) and number of strands (or phases) of the study (mono strand or multi strands).The first criterion concerns whether the study involves employing only one method (quantitative or qualitative) or both methods (quantitative and qualitative). The research designs in which only either quantitative or qualitative methods are employed across all stages of the study are called mono-method designs, whereas research designs in which both quantitative and qualitative methods are combined across some stages of a study are referred to as mixed-methods designs. The second criterion is related to whether the study involves only one strand (phase) or multiple strands (phases). Phases refer to the three stages mentioned above: the conceptualization stage, the experiential stage and the inferential stage.

As can be seen in Table 13, there are four cells in the matrix, but as this is a mixed-methods study I will focus on the bottom two cells only (cells three and four in Table 13). The matrix provides two types of mixed-methods designs: mixed-methods with only one strand (cell three) and mixed-methods with multiple strands (cell four).

Cell three refers to mixed-methods designs in studies that involve only one strand. There are two families of these designs, namely: mono-strand quasi-mixed designs and mono-strand conversion designs. Quasi-mixed designs collect both qualitative and quantitative data, but no integration of the findings occurs. In contrast, conversion designs convert one form of data into the other form and then analyse accordingly. For example, this might include converting narrative data into numeric data using frequency counts, then analysing the converted data quantitatively.

Cell four refers to mixed-methods multi-strand designs, and my study can be considered as an example of this. Mixed-methods multi-strand designs contain mixed methods in at least two phases. There are four families of these designs (each may include numerous permutations of designs): concurrent, sequential, conversion and fully integrated.

The concurrent mixed-methods multi-strand design is a design in which there are at least two independent phases: one with qualitative questions, qualitative data and qualitative analysis, and the other with quantitative questions, quantitative data and quantitative analysis. Each form of data is analysed independently, and conclusions are drawn separately. In other words, the two phases of the study are kept independent until all data analyses are finished. Mixing happens at the inference stage.

To a large extent, my study is an example of a concurrent mixed design because it involved two relatively independent phases, both quantitative and qualitative. The first phase resulted in collecting qualitative data through semi-structured interviews with lecturers in two departments of mathematics, while the second phase resulted in collecting quantitative data by distributing a questionnaire to lecturers of mathematics at eight universities in Saudi Arabia. These two phases yielded two types of data: qualitative and quantitative. Data were collected and then analysed independently. Data analysis was conducted separately and integration occurred at the data interpretation stage. The findings of the two phases were integrated by comparing the two findings to try to construct a fuller picture of the issue of software use by mathematical lecturers in Saudi Arabia.

The sequential mixed-methods multi-strand design is a design that involves at least two phases that occur sequentially (quantitative followed by qualitative or qualitative followed by quantitative). The conclusions that are made on the basis of the results of the first phase lead to the formulation of research questions, data collection and data analysis for the next phase. The final inferences are based on the results of both phases of the study. The second phase is conducted to either confirm or disconfirm the inferences of the first strand or to provide further explanation of the findings from the first strand. My study is not sequential because the qualitative and quantitative phases were relatively independent of each other.

The conversion mixed-methods multi-strand design is a multi-phase design in which combining quantitative and qualitative data occurs in all stages of the research, with data transformed and analysed both thematically (qualitative) and statistically (quantitative). One type of data (e.g. qualitative) is collected, analysed accordingly (qualitative) and then transformed into the other type (quantitative) and analysed accordingly (quantitative). Thus, one type of data (e.g. qualitative) is subjected to both qualitative and quantitative analyses and inferences are conducted using both types of data. Again the current research does not follow this design since data transformation, where one data form is converted into the other and then analysed both qualitatively and quantitatively, did not occur at any stage of the research.

The fully integrated mixed-methods multi-strands design, which is the most complex design in the matrix, is a design in which there is a series of phases and the mixing of qualitative and quantitative data alternate in an interactive and dynamic way at all stages of the research. In these designs, the two types of data interchange with one another reciprocally at all stages of the research. At each stage, one approach (e.g. qualitative) affects the formulation of the other (quantitative). The two phases in the current study are relatively independent and therefore this is not a fully integrated study.

My general position is to prefer a more fully sequential approach than that followed here, because this would allow better use of the themes that arose from the interviews in the design of the survey. In fact, the findings of the interviews were partially used in the survey redesign, and my final survey would have been much poorer without that input. However, an opportunity to fully identify the themes of my survey in advance of its implementation was perhaps missed. The reason for this was that I was compromised by practical considerations (I had permission to carry out the survey at a particular time and during a pre-planned visit to Saudi Arabia); in research, many decisions are based on the art of the possible.

3.4 Research design

To recap, the current study is a large-scale mixed-methods study within a post-positivist tradition. This study sought to examine how and why mathematics lecturers at Saudi universities use software for teaching. The stimulus for this study came from my own experience of teaching (as described in chapter 1) and my belief that technology could help in the improvement of the mathematics curriculum. I came to see my local knowledge in a much wider context through my reading of the literature and the highlighting of the key themes of access, training and support, curriculum, perceptions of software, confidence, competence, wider environment and pedagogical beliefs.

Using the terminology of Teddlie and Tashakkori (2006), the appropriate description of the overall design of this research is a concurrent mixed-methods two-strand design. This means that this research involved two relatively independent phases (two-strand), quantitative and qualitative. These two phases yielded two forms of data: qualitative and quantitative. Data were collected and then analysed independently. Data analysis was conducted separately and integration occurred at the data interpretation (inference) stage. The findings of the two phases were integrated by comparing the two findings. The rationale for the use of a mixed-methods design in this study can be summarized as follows: 1) because both types of data, together, will provide a better understanding of the issue of software use by mathematical lecturers than either type by itself; 2) the survey data will provide an overall picture of software use in the teaching of university-level mathematics in Saudi Arabia, whereas the interview data will explain this overall picture in more detail; 3) the interview data will provide solid descriptions of the settings and uncover different factors affecting the use of software, while the survey data will test associations and establish relationships between the different variables; and 4) as mentioned by Yauch and Steudel (2003), data obtained from the two phases can be used either to enhance triangulation (if the evidences are consistent in both phases) or to complement each other (if there is no consistency between the evidences in the two phases).

This research was comprised of a qualitative phase (semi-structured interviews) and a quantitative phase (questionnaires). The semi-structured interviews aimed primarily to explore the views of mathematics lecturers on how and why they use software in teaching undergraduate mathematics and statistics. The survey was a means to reach the largest possible number of lecturers in the country and to extract further evidence, especially about the factors that may encourage or discourage lecturers from teaching mathematical courses using mathematical software. Data analysis was performed in which the themes obtained from the qualitative phase were compared and contrasted with the findings from the quantitative phase. The consistency between the findings of the two phases strengthened the evidence of the research.

One phase of the study was exploratory in nature, utilizing semi-structured interviews to examine several questions related to software use by mathematics lecturers at universities in Saudi Arabia. The semi-structured interviews mainly examined the following questions:

- What is the context in which lecturers use ICT in the teaching of university-level mathematics?
- How do lecturers use mathematical software in the teaching of university-level mathematics courses?
- What encourages/motivates lecturers to use software in the teaching of university-level mathematics courses?
- What discourages/constrains lecturers from using software in the teaching of university-level mathematics courses?

The other independent phase in this research utilized a quantitative (survey) approach. The survey sought to collect responses from the wider population of mathematics lecturers at well-established universities in Saudi Arabia. In this quantitative phase the goal was to answer the above questions in addition to the following two questions:

- How, and to what extent, do lecturers use mathematical software in the teaching of university-level mathematics courses?
- Do particular individuals or groups of mathematics lecturers use software more than others?

The interconnectedness of the research questions, the literature review and the methods used is highlighted below.

RQ1. How, and to what extent, do lecturers use the software in the teaching of university-level mathematics courses?

The literature suggests	Interview	Survey
• Limited use of software (p. 45) • The impact of digital technology on the learning and teaching of mathematics and on mathematics curricula has been questioned (pp. 39-41) • Primary purposes are quick calculation, visualization, and multiple representations (pp. 47-51) • ICT can be used in a more general sense to support teaching (e.g. pp. 54-57) • Easy access does not guarantee use (p. 41)	Do you usually use projection technology in your teaching? Do you use software in your teaching? Can you give examples of software use from your teaching?	• In a typical academic term, in about which percentage of your lectures do you use mathematical or statistical software? • how and where do you use software (in a lecture room, in a computer lab, I assign homework which requires use of software) • I use software for (visualization, symbolic manipulation, numeric computation, statistical analysis, as a programing language) • Which software package do you usually use in your teaching? (Matlab, Mathematica, Maple, SAS, SPSS, etc.) • Do you use presentation software (e.g., PowerPoint), smart Board in your teaching? • Do you use VLE software (e.g., Web CT, Blackboard, Moodle) • I use VLE for: (e.g. posting lecture notes, emailing students, discussion forums).

RQ2. What is the context in which lecturers use ICT in the teaching of university-level mathematics?

The literature suggests	Interview	Survey
• Developing wider use of technology is influenced by both access and social-cultural issues (p. 40) • Integrating software requires changes to the curriculum and assessment (pp. 57-61) • Training courses for teachers must focus on the technical aspects of ICT as well as on pedagogical practices in integrating ICT into the curriculum (e.g. pp. 42, 68)	• How do you describe the ICT infrastructure for teaching and learning mathematics in this department? • In mathematics curriculum at this department, what is the scope of software use? (Is it implemented in one, more than one course, or in all courses?)	• Projection systems are available in most lectures rooms • It is not difficult for me to schedule a class in a computer lab when I want to • I have access to the software packages I need for teaching • I have access to technical support if I need it • I find the appropriate software difficult to access in my university • Most entry level classes are too large for the available computer labs • Have you ever participated in any technology training provided by your department or elsewhere? • I would be happy to attend technology training workshops • There is enough training for lecturers who want to teach with software • There is too little support for lecturers who want to integrate software in their teaching • There isn't enough time to incorporate software into math curriculum • My department encourages the use of software in teaching • The majority of faculty members within the math department are users of software in their teaching • Only a few of my colleagues are enthusiastic about using software in their teaching

RQ3. Do particular individuals or groups of mathematics lecturers use software more than others?

The literature suggests	Interview	Survey
• Age, teaching experience and gender of teachers might play a role on their use of ICT when teaching mathematic (p. 25) • Mathematics is not a unitary subject-it has some computational as well as theoretical elements (pp. 31-35)	• What is your research area in mathematics? • How many years teaching experience do you have at university? • What are the courses you usually teach? And what are the levels of these courses? • What students do you usually teach (i.e. mathematics or non-mathematics majors)?	• What is your gender? • How many years have you been teaching university-level mathematics (statistics)? • Please indicate your main research interest • I used software when I was a student (yes or no) • Do you normally teach (mathematics students, statistics students, introductory courses for students of different subjects) • Do you normally teach (first year undergraduate courses, second year undergraduate courses, third and/or fourth year undergraduate course) • Which courses are you teaching this year? (Calculus, abstract algebra, linear Algebra etc.)

RQ4. What encourages/motivates lecturers to use the software in the teaching of university-level mathematics courses?

<table>
<thead>
<tr><th>The literature suggests</th><th>Interview</th><th>Survey</th></tr>
</thead>
<tbody>
<tr>
<td>External (first order):

Access (e.g. pp. 67-69)
Training and support (e.g. pp. 68-69)
Curriculum and assessment aligned and time (e.g. pp. 63-64)
Wider environment (pp. 66, 70)

Internal (second order):

Beliefs about mathematics and how it is best learned and taught (e.g. pp. 63, 70-71)
Perceived benefits of software (e.g. pp.47-51, 65, 67)
Competence (e.g. pp. 64, 66)
Confidence (p. 64)

</td>
<td>

Why do you use software in your teaching?
How do you view the effect of software technology on mathematical learning /teaching/understanding? (Potential benefits of software in math)

</td>
<td>

Access:

I have access to the software I need for teaching
It is not difficult for me to schedule a class in a computer lab when I want to

Training and support:

There is enough training for lecturers who want to teach with software
I have access to technical support if I need it

Curriculum, assessment, and time:

the courses I teach do not require the use of software
students do not pay attention to the use of software because it is not included in tests
there isn’t enough time to incorporate software into the curriculum

Perceived benefits:

software use helps to refocus teaching away from time consuming calculation

Competence and confidence:

I don’t know how to integrate software into my teaching
I don’t feel confident using software in my lecture

Wider environment:

My department encourages the use of software in teaching

Pedagogical beliefs:

Which better fits you? (lecturer should facilitate learning, rather than teach directly, or lecturers should teach directly rather than just facilitate

</td>
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</table>

RQ5. What discourages/ constrains lecturers from using the software in the teaching of university-level mathematics courses?

<table>
<tr><th>The literature suggests</th><th>Interview</th><th>Survey</th></tr>
<tr><td>External (first orders):
Lack of access (e.g. pp. 63, 64)
Lack of support (e.g. pp. 63, 64, 66, 85)
Lack of relevant training (CPDs) (e.g. pp. 63, 64)
Curriculum and assessment not aligned (e.g. pp. 58, 66, 70)
Lack of time (pp. 64, 86)
Wider environment (pp. 66, 70, 80)
Internal (second order):
Beliefs about mathematics and how it is best learned and taught (e.g. pp. 70-71)
Perceived drawbacks of software (e.g. pp. 52-53, 66)
Lack of competence (e.g. pp. 52, 64)
Lack of confidence (p. 63)</td><td>Why don't you use software in your teaching?
What do you think are the barriers or obstacles to better technology integration in learning and teaching university mathematics?
Some mathematicians fear that the use of technology when learning mathematics might weaken students understanding of basic ideas in mathematics, what is your view on that?</td><td>Lack of access:
I find the appropriate software difficult to access in my university
Lack of support:
There is too little support for lecturers who want to integrate software in their teaching
Lack of relevant training:
There is enough training for lecturers who want to teach with software
Curriculum and assessment not aligned
The syllabus in the undergraduate mathematics program limit the use of software
It is difficult to assess what students know if they can use software in tests
Lack of time:
It takes too long to develop software-related teaching materials
Wider environment:
Only a few of my colleagues are enthusiastic about using software in their teaching
Perceived drawbacks:
I think using software in teaching distract students from understanding mathematical concepts
Lack of confidence:
I don't feel confident using software in my lectures
Lack of competence:
I don't know how to integrate software into my teaching</td></tr>
</table>

A timeline of the experiential stage of this research is provided in Table 14. This shows that the experiential (data collection and data analysis) stage of the study involved semi-structured interviews conducted in April and May of 2011 and a questionnaire administered in March and April of 2012. An interview was piloted with two Saudi lecturers studying in the UK in February and March of 2011. In April and May of 2011, 18 lecturers from 2 mathematics departments were interviewed (9 lecturers from each university). From June to December of 2011, the interview transcription and analyses were conducted using Nvivo. A questionnaire, which was based on Lavicza (2010), was piloted in June of 2011, and in the first quarter of 2012 it was redesigned. The final version was administered in hard copy to lecturers at four universities and on-line to lecturers at another four universities. The returned questionnaires were analysed using SPSS in May, June and July of 2012.

Table 14: Timeline of the experiential (methodological and analytical) stage of my research

Time (Month, year)	Activity	Notes
February–March (2011)	Pilot interview	Interview was piloted with two Saudi lecturers studying in the UK
April	Interview university A	Nine lecturers (two lecturers from pure math, one from applied math, two from computational math, four from statistics)
May	Interview university B	Nine lecturers (two lecturers from pure math, two from applied math, two from computational math, three from statistics)
June–August	(Pilot) questionnaire (based on Lavicza (2010)) Interview transcription and analysis	Questionnaire was e-mailed to nearly 150 lecturers (35 completed the questionnaire)
September–December	Interview analysis	Nvivo was used for analysis
January–March (2012)	Re-designing the questionnaire	Items about presentation software and LMS were added Items about mathematics, mathematical abilities, mathematics learning and teaching were added
March–April	Questionnaire was administered (4 universities-printed version and 4 universities-on-line version)	- Total recipients of printed version were 170 lecturers (4 universities)-109 responded - Total recipients of online version were 251 lecturers (4 universities)-42 responded -Overall response rate was 35.8%
May–July (2012)	Questionnaire analysis	SPSS was used for the analysis

These phases can be considered as lying within an overall study design as shown in Table 15. The conceptualization stage of the study involved reviewing previous literature and generating the research questions; the methodological and analytical stage were carried out in two consecutive phases. In the first phase of data collection face to face semi-structured interviews were used and in the second phase a questionnaire survey was carried out. The data were analysed thematically (in the first phase) and statistically (in the second phase). The findings from both phases were integrated and conclusions were drawn.

Table 15: the overall design of this study

<table>
<tr><td colspan="2">Conceptualization stage:
Review of literature
Generating the research questions</td></tr>
<tr><td colspan="2">Design: (partly) concurrent mixed methods two strands design</td></tr>
<tr><td>The first phase</td><td>The second phase</td></tr>
<tr><td>Methods stage: interviews</td><td>Methods stage: questionnaire</td></tr>
<tr><td>Analytical stage: interview analysis (Extracting themes)</td><td>Analytical stage: questionnaire analysis (statistical analysis procedures)</td></tr>
<tr><td>Inferential stage (interviews findings)</td><td>Inferential stage (questionnaires findings)</td></tr>
<tr><td colspan="2">Integrating the findings from both phases
Conclusions</td></tr>
</table>

The qualitative phase: Semi-structured interviews

This research employed semi-structured interviews as a method of collecting data from lecturers in the first phase of the study. Interviews as a method of data collection may lie at a different position in the continuum of quantitative-qualitative approaches to research. Interviews can be highly structured, semi-structured or unstructured (Scott and Morrison 2007). Interviews produce different types of data depending on the purposes for which they are designed. Kvale and Brinkmann (2009) assert that by employing semi-structured interviews, researchers attempt to understand the lived everyday world from the participants' own perspectives. They argue that research interviewing should be regarded as a craft more than a method. Learning the craft of interviewing is done by practicing interviewing. There are no explicit predetermined steps when conducting an interview, but it always depends on the practicality of a given situation.

As Kvale and Brinkmann (2009) explain, the process of knowledge construction through interviewing is subjective and social, involving interviewer and interviewee as co-constructors of knowledge. Different interviewers may have different statements on the subject they are examining because they have varying levels of knowledge and experience. Most of the knowledge produced by interview research is about people's experiences and opinions. This kind of knowledge represents 'doxa' (simply opinions with no validation) and 'episteme' (knowledge that has been found to be valid). Two contrasting metaphors for the interviewer are proposed by Kvale and Brinkmann. The first is the interviewer as a miner and the second is as a traveller. In the miner metaphor, the epistemological conception of interviewing can be seen as a process of knowledge collection (knowledge as buried metal), whereas the traveller (explorer) metaphor yields a process of knowledge construction. The knowledge in the first metaphor is given and in the second it is constructed. Kvale and Brinkmann suggest that the interviewer seeks to obtain an accurate description of the interviewee's world from which an accurate interpretation can be drawn. They add that the interviewer should avoid presupposition about the subject's life world, but there must be a focus on specific themes to guide the conversation.

In my study, the interviews were designed, conducted then analysed based on the five stages of an interview investigation, which are given by Kvale and Brinkmann (2009): thematizing, designing, interviewing, transcribing and analysing. Here is a brief description of each:

1. Thematizing (the ‘why’ and ‘what’ of investigation before the ‘how’) refers to identifying the topic and the purpose of investigation (the ‘why’), and developing knowledge of the phenomena under investigation (the ‘what’).
2. Designing (the ‘how’) involves thinking about and pre-planning the design of the study (e.g. planning to conduct 18 interviews, and thinking about the time and resources involved). The number of interview subjects should be enough to obtain the intended knowledge. Designing also involves thinking through the ethical implications.
3. Interviewing involves conducting the interviews based on an interview guide indicating the topics that will be discussed in a logical order. The interview questions should be brief, simple and dynamic, providing positive interaction and flow; ‘a good interview question should contribute thematically to knowledge production and dynamically to promoting a good interview interaction’ (p. 131).
4. Transcribing, which is translating oral interview conversations to written texts, prepares the interview materials for analysis.
5. Analysis of the interviews should not be an independent stage, but the researcher should think of how the analysis should be done at an early stage. Based on the purpose, topics and nature of the interview materials, the researcher decides which methods of analysis are appropriate. Meaning coding, meaning condensation and meaning interpretation are three common methods of analysis in interview research. Coding involves assigning keywords to a text segment with the goal of sense making, organizing and categorizing the narrative data. Condensation is when the researcher rewrites long statements expressed by interviewees into shorter ones with the aim of concentrating

the meaning into fewer words. Interpretation is when the researcher interprets the implicit meaning of what has been said by the interviewees.

Thematizing and designing the interview schedule

The purpose for conducting the interviews was to establish knowledge regarding how and why mathematical lecturers use (or do not use) mathematical software in the teaching of mathematics courses at the university level in Saudi Arabia. Based on this general purpose, an interview schedule was prepared containing four main themes: the use of software (the 'what', 'how' and 'where' questions, etc.); the value of software use (the 'why'); the barriers to software use (the 'why not'); and the issue of overreliance on technology, which proved to be a major hindrance to software use, stemming from the literature (e.g. Buteau *et al.* 2010) (see Appendix 1: Interview Schedule).

Interviewing

As for the interviewing, which is the third stage of interview investigation, in February and March of 2011 an interview schedule was piloted with two lecturers of mathematics studying for PhDs in the UK. The interviews lasted for about one hour and both lecturers thought that although the questions were clear, some questions could have been grouped together to reduce the time required to conduct the interview. In April and May of 2011, two mathematics departments were selected at two major universities in Saudi Arabia. These departments were chosen purposively. It was speculated that the first university, from which I graduated, was likely to be a 'low user' of ICT in the teaching of undergraduate mathematics courses in general and in mathematical software, in particular. On the other hand, it was well known that the second university, which is more specialized in the field of science and engineering, was a leading university in the country in the use of technology.

Criteria for the selection of interviewees

At each university visit, in-depth interviews were conducted with lecturers from different branches of mathematics (i.e. pure mathematics, applied mathematics, computational mathematics and statistics). The heads of the mathematics departments were consulted first to determine a group of faculty members from different branches of mathematics who they felt may be willing to talk to me. This then can be described as both a purposive and an opportunistic sample. Subsequently, a subset of nine lecturers was selected for interviews. The goal was to interview a large group of lecturers from different branches of mathematics and from two different departments of mathematics in order to obtain a variety of perspectives from two different contexts on the topic. Therefore, the lecturers who were interviewed were selected according to two main criteria. The first criterion was that they belonged to different branches of mathematics (pure mathematics, applied mathematics, computational mathematics and statistics), and the second criterion was that they were likely to talk to me about software in teaching. This may suggest a bias towards lecturers who were familiar with the use of software, but the data analysis showed very divergent views on the use of software and very different experiences.

Conducting the interviews

Lecturers were interviewed individually after arranging appointments during working hours. It was believed that the offices of the respondents were suitable for lecturers to give their views without interruption. Each interview began with a brief introduction defining the objectives of the interviews, and pointing out that mathematicians generally can be classified as belonging to one of three groups when it comes to using software in mathematics: those who strongly endorse the use of software in the learning and teaching of mathematics; those who are strongly against the use of software when learning and teaching mathematics; and those who are in between these two views, tending toward one of the two groups.

Being a graduate of mathematics from a Saudi university and now a lecturer of mathematics at a Saudi higher educational institution, I was familiar with the context of mathematics teaching at universities in Saudi Arabia. My knowledge of the topic and my familiarity with the participants and the context helped in easing the interaction between myself and the interviewees and allowed me to pose relevant, direct and specific questions, and enabled me to follow-up or probe whenever it was necessary. Box 1 shows an excerpt from an interview with a lecturer (from the Department of Mathematics B).This shows my probing and asking the lecturer to explain the way in which he used mathematics software during his teaching and whether students used the software. I then asked him to give an opinion on why the use of software was not common in the teaching of mathematics (the uppercase Q shows my questions, while the uppercase A indicates the interviewee's responses).

Q: What about the teaching setting? Do you use software in the lecture room or in a computer lab?

A: I use it in the lecture room. We don't have a lot of computer labs where I could; I would love to take my students to a computer lab where everybody would be setting on the computer and pretty much doing whatever I am doing. However, we have smart rooms and I just use the projector and explain the steps but then later on I give them some work to do on their own, and if they need help they could come to my office and I help them. But I do not use them in the computer lab because of the facilities here. We don't have enough but I would love to have my lectures in a computer lab.

Q: OK, regarding your students, were they happy with the use of packages?

A: I used it last week where we have a curve and we rotate the curve to get a solid, believe me they were extremely happy when I showed them the cross sections and the cylinders we were building to get an estimate for the volume. They were extremely happy I could tell, I asked them they wanted to integrate technology in the classroom.

Q: What about, Doctor, if your students wanted to use technology, does the department provide them with computer labs?

A: Really to be honest with you, using technology in our courses here unfortunately is not very famous.

Q: Do you mean in mathematics?

A: In mathematics, using technology in our undergraduate courses is not very famous.

Q: I think this is worldwide; some mathematicians are reluctant to use technology. I don't know why. Do you know what might be the reasons?

A: With all due respect to our colleagues we have two kinds of generations: older generations they prefer the traditional way of teaching; the newer ones I think they would go for technology.

Q: Do you think this is the only factor or maybe their teaching experience?

A: There are other factors; it depends on their background. Even the area of their research sometimes leads them to traditional way of teaching or to go for technology.

Q: For example?

A: If somebody is in pure mathematics never use technology in his research maybe he doesn't appreciate the use of technology but if your area of research is computational mathematics or applied mathematics where without the use of computer, it would be impossible for you to do huge calculation then you really value these packages. Then you would try to integrate technology in the classroom. So a lot of factors: I would say generation, traditional way of teaching versus innovative way of teaching and things like how much you are willing to. Also, you need to add another factor: here at [the name of the university] there is more emphasis on research. So would faculty spend some time on thinking, 'How do I improve my teaching style?'

Q: You mean their time is spent more on research?

A: Well, I will give my lecture. Who cares as long as I am doing my research?

Box 1: An excerpt from an interview with a lecturer (B2)

Each of the interviewed lecturers was asked whether he would have preferred to conduct the interview in English or Arabic. Fourteen of them preferred to conduct the interviews in English, while only four lecturers preferred to conduct interviews in Arabic. I did not find any differences between these four interviews compared to the interviews that were conducted in English. The interviews varied in their lengths, as well as in the quality of responses the interviewees provided. Some interviews lasted about 15 minutes, while others lasted a little over an hour. Some of the lecturers gave brief answers while others gave prolonged accounts and a variety of ideas about the use of software, illustrating with specific examples of how the software was used to clarify some of the topics in mathematics. For example, two of the lecturers, one in each university, agreed to take me to the lecture hall and show me examples of how they explained some mathematical concepts using software.

At this point I would like to discuss the lack of formal observational data in my study. As I was conducting the interviews, two interviewees, who were the only frequent users of software, invited me to visit the facilities and look at the software installed on the machines. Also, I inspected documents such as course contents, lecturers' webpages, and mathematics departments' websites. I also inspected VLEs and looked at activity, and I informally talked to students about their use of software and about their use of VLEs. As it is, I thought it would be unethical to observe lecturers who declined to be observed. However, one of the important points here is that I had a good understanding of the context as I was a graduate of one department and I studied for a summer term in the other department. I also had recently taught as a lecturer in one of these departments for six years and I have a good understanding of the context. During each university visit, I informally observed many classes, talked to students and had first-hand experience of the facilities.

Transcribing and analysing the interviews

After obtaining the consent of all the participants, the interviews were recorded using a digital voice recorder. The interviews were then transcribed and coded, and comments were grouped using the software NVivo. After reading the transcripts and my own observations and notes, the narrative data were coded and re-coded several times (one of the initial coding schemes is shown in Box 2). The initial coding scheme involved 4 main themes: use of mathematical software (7 subthemes), reasons for use of software in teaching (the benefits of using software) (16 subthemes), reasons for non-use of software in teaching (barriers to the use of software) (16 subthemes) and general views of ICT (8 subthemes).

A. Use of mathematical software:
   1. Examples of software use (what: e.g. MATLAB, Excel, Maple, SAS)
   2. Examples of software use (where: a. lab b. lecture room c. homework project)
   3. Examples of courses in which software is used or not used (e.g. numerical, calculus)
   4. Learning management systems
   5. Instructional purposes of software use
   6. Scope of software use in math/stat curricula
   7. Voluntary vs. mandatory use

B. Rationale: (why-values of software use):
   1. Because it is on the course's syllabus
   2. Because it offers automated features
   3. It assists visualization
   4. It assists with computations/programing (procedural or technical work)
   5. It makes things clearer (conceptual understanding)
   6. It engages students
   7. Saves me time
   8. I have good access/training/technical support
   9. I believe it makes a difference (students benefit from it)
   10. I like it—I identify myself as an ICT person
   11. The university encourages me
   12. In some courses it is applicable
   13. It is assessed
   14. It is quite easy to use (user friendly)
   15. Supplementary tool/as an aid to learning and teaching

16. Accessible to a large audience/repository

C. Why not: (barriers to software use):

1. No time
2. All a black box—overreliance on it
3. Math is about concepts not techniques
4. The university (department) discourages me
5. In some courses not applicable/essential
6. Not in the syllabus/text book
7. Too little access
8. I lack the skills and training
9. Students lack the skills and training
10. Not assessed and cannot be assessed
11. Software is not user friendly
12. Presentations should be rough and ready (whiteboard)
13. Learning requires effort
14. It is difficult for individual lecturer to design course materials that involve the use of software/need of collaborative work
15. Unsure how to teach using software
16. Coordinated classes

D. Lecturer's conceptions (views) of:

1. Undergraduate mathematics/statistics
2. Values of software packages in teaching/learning mathematics/statistics
3. Ideal teaching strategies (with or without technology)
4. Factors influencing software use
5. Differences between software use in Saudi Arabia and outside Saudi Arabia
6. The issue of overreliance on the software
7. Use of software in examinations (evaluations and feedback)
8. Students' skills/knowledge/needs

Box 2: An initial coding of the interview data

After rounds of coding and re-coding and applying these codes to the interview transcripts, the data were eventually coded into three main themes: use of mathematical software including learning management systems (LMS), rationale for use of software in teaching (cognitive or contextual reasons) and rationale for not using software in teaching. This was finally organized as in Box 3.

A. Use of software

1. What (e.g. MATHEMATICA, MATLAB, Maple, SAS)
2. Where (e.g. lab, lecture room with OHP, exercise sessions, HW, exam)
3. Course (e.g. numerical analysis, calculus, statistics)
4. Topics in which software is used
5. LMS
6. Scope of software use in math/stat curricula

B. Rationale: (why-value of software)

Cognitive-contribution to learning/understanding

1. It offers speed automated features
2. It assists visualization
3. It makes things clearer (conceptual understanding)
4. It engages students

Extends and expands

5. Anywhere any time access
6. Students can shares ideas within a forum

Contextual consideration

7. I have good access to equipment, training and technical support
8. The university encourages me
9. In some courses it is very applicable (e.g. stats) and in the syllabus
10. It is quite easy to use ICT
11. Students find it easy to use ICT (e.g. they have the background skills)
12. Students have access to ICT
13. Vocational/professional preparation (e.g. they might need to use it later in life)
14. Saves me time in my teaching (e.g. reuse PowerPoints, mail out to everyone)

C. Why not (barriers to software use)

Cognitive considerations

1. All a black box—overreliance on it

2. Math is about concepts, not techniques
3. Presentation should be rough and ready (using chalk) as this makes it easier for the students to interact and reflect
4. Learning requires effort

Contextual considerations

5. No time to deviate from the syllabus
6. The university (department) discourages me
7. Not in the syllabus
8. Too little access to ICT
9. I lack the skills and training to use the software
10. Students lack the skills and training
11. ICT use is not assessed
12. It is difficult for individual lecturers to design course materials that involve software
13. The prevailing culture is not very positive to ICT

Box 3: The final coding scheme of the interview data

Regarding how data were coded using this coded scheme using Nvivo:

1. The data were entered into Nvivo.
2. Each unit of meaning was tagged with one or more codes (node is the name used for code in Nvivo).
3. Coded data were aggregated for ease of use.
4. Each coded section was written up in a descriptive report.

In Box 4, an excerpt extracted from Nvivo regarding the theme 'Why not: It is all a black box—overreliance on technology'.

<Internals\\ksuc1> - § 2 references coded [7.64% Coverage]

Reference 1 - 5.49% Coverage

A: If you use it like a black box, I call two approaches if you use technology as a black box that is distractive, you know?

Q: Yes.

A: Because anyone can press on that and get that.

Q: Yes, without appreciating the concepts.

A: And the building of e-slaves, the building of that icon which you press on, unless you know how to build it and that is what I am calling for; learning through building. Unfortunately this black box is a killing, you know, for thinkers, for the minds, and unless we move to in to the construction and see these things in a glass box approach, see how it works, at least see how it works, think about how it works, if you can't produce it, yes I know producing such systems is not individuals it needs team works and still we are too far away from that and that's what we need to build if we really want learning with technology, but what I am calling for is at least think about it simulate it and create the role.

{ HYPERLINK "file:///G:\\28a93f2c-e423-45f3-a4ce-986587dc30cd" **}** - § 2 references coded [6.81% Coverage]

Reference 1 - 2.10% Coverage

A: Being primitive means that you are in charge of everything, you're in charge of the whole operation from A to Z. However, in other more advanced software like Mathematica or MATLAB, one statement could do everything but you don't know the inner workings.

Q: Ok.

A: Of the package or the software or the procedure, what actually goes inside the computer; you don't know and you cannot easily control it.

Reference 2 - 4.71% Coverage

Q: So can you see the value of the use of software as a mathematician and as a lecturer of mathematics?

A: Frankly no, I think it is counter-productive.

Q: Ok.

A: When you teach a student an introductory course in differential equations and you tell them that here is the way we solve a first order differential equation, for example–

Q: ODE

A: yes, you spend one lecture explaining how to solve it, how to produce the integrating factor and all these steps and then you tell the students there is a package that can do all that, well they will take the package and leave.

Reference 2 - 1.92% Coverage

A: Exactly, you want to use Mathematica to help you do mathematics Mathematica, or you want to replace mathematics, but there is no clear border between the two.

Box 4: An excerpt from an Nvivo window (regarding the node: 'overreliance on technology')

The reporting of the interview data is presented in two parts (pp. 150-181). In part 1, I presented an overview of ICT resources and described the undergraduate mathematics and statistics programmes at the two departments. In part 2, I discussed the use of software, as well as the rationale for using or not using software. In terms of the use of software, I discussed how software was employed in the two departments in terms of the following: the types of software packages used, the courses in which software was used (or not used), examples of taught topics in which software was used, where software was used including the use of software in assessments and the use of the VLEs. On the other hand, in relation to rationale for using software, I discussed value for learning and teaching, motivational value and contextual encouragers. Value for learning and teaching covered software as offering automated features; visualisation; a better focus on understanding concepts and/or helping different types of learners; and saving lecturers' time in their teaching. Motivational value covered the engagement of students. Finally, contextual encouragers were easy access to ICT; university encouragement for the use of ICT; and ease of use. In terms of the rationale for not using software, I discussed doubts about the value of software and contextual problems. Doubts about the value of software covered: presentation should be rough and ready (using chalk); students could become over-reliant on the software and the general idea of black box use of software; and students needed to make the effort and spend more time learning mathematics from first principles before resorting to ready-made functions. The contextual barriers were as follows: software is inappropriate for some courses, namely those concerned more with theory than technique; a curriculum with heavy and fixed content; software which was not assessed in many cases; lack of cooperation between lecturers to produce curricula which included the use of software; and the prevailing culture in mathematics departments.

The quantitative phase: The survey

This research involved a cross-sectional survey of lecturers of mathematics at universities in Saudi Arabia. The term 'survey' generally refers to both a research strategy and research method of collecting data from a relatively large sample in a systematic way (Scott and Morrison 2007). As mentioned by Guyette (1983), the cross-sectional survey is an approach to conducting a survey where data are collected at one point in time. When the data from a cross-sectional survey are analysed, the results can vary from tabulations and descriptive statistics to inferential statistics.

The survey (or questionnaire) was administered to lecturers in departments of mathematics and statistics at well-established universities in Saudi Arabia. As previously mentioned, the questionnaire was administered to a total of 421 lecturers from the departments of mathematics and statistics at 8 state universities. At the time of the research (March- April 2012) these eight universities were more established, and since carrying out the research new departments have been set up, but time constraints and lack of access to such departments impeded my quest to involve them in the research. The questionnaires were delivered in hard copy format (printed versions) to a total of 170 faculty members, and via e-mail to a further 251 lecturers. In Chapter 5, using the survey's findings, I give an overview of how lecturers with research interests in pure, applied, computational mathematics and statistics used software packages in their teaching, and the rationale for ICT use. In addition, using the lecturers' responses to the survey, I explore associations between the use of mathematical software and a variety of variables such as teaching experience, area of research, nature of course, nature of students and access to ICT facilities. Even though the data were collected at one point in time with this cross-sectional survey, this survey involved items looking for change. For example, there were items asking about events in the past, present and future. The responses to such questions can provide a basis for looking at change.

The population of the study

The population, as indicated earlier, was lecturers of mathematics in established departments of mathematics at state universities in Saudi Arabia. These universities are spread over different parts of the kingdom. All these universities are under the direct supervision of and receive support from the government, represented by the Ministry of Higher Education.

Piloting the questionnaire

A questionnaire was piloted in June 2011 with 35 faculty members from various mathematics departments, based on the survey conducted by Lavicza (2010) in his international comparative study in the UK, US and Hungary (see Appendix 3). The first seven questions of the pilot questionnaire asked for demographic information from the respondents, for example, their gender, teaching experience, main research interests, use of software in research, taught students and taught courses. The second three questions in the pilot questionnaire asked about access to software, technical support and technology training accessed through the respondents' organisations or elsewhere. The third part asked about the 'how' of using software in teaching. This included questions about the percentage of lectures in which software was used, the types of software packages employed during teaching, the teaching setting in which software was used, the purpose of using software during teaching, the type of students with whom software was employed, the level of courses in which software was used and whether the use of software was permitted during assessment. The last part of the pilot questionnaire asked about the factors that may influence lecturers' decision to use or not to use software when teaching university mathematics. These factors included software syntax being too complex, entry-level classes being too large to use software, colleagues being less enthusiastic about the using software, the course schedule being too tight, the lack of availability of software in respondents' organisations and difficulties in assessing what students know if they can use software in tests.

After conducting the pilot questionnaire and reflecting on the interview data, two issues arose. First, the questions in the pilot questionnaire were mostly about 'who' used the software more in teaching and 'how' software was used; there were fewer questions about 'why' or 'why not' software was used (or not used). In the pilot questionnaire, only in the last part were some of the factors that may encourage or impede software use explored. While acknowledging that curriculum, assessment, class size, time and departmental influences were important, the pilot questionnaire lacked items which focussed on respondents' views concerning the nature of mathematics at the university level and the role of technology when learning mathematics. It also glossed over attitudes to ICT use, which proved to be an important issue within the interviews. The final version addressed these issues.

Second, after piloting, it became apparent that not only did the content in the questionnaire need to be modified, but also that there was a need for a better layout and simpler and clearer introduction to clarify the questionnaire objectives. Thus, the redesign of the questionnaire enabled me to have more confidence that the questions were clear, addressed the aims of the study and would enable me to obtain data about lecturers' beliefs concerning mathematics teaching and their attitudes towards ICT. Table 16 shows the overall changes that were made to the questionnaire after piloting it.

Table 16: Changes made to the questionnaire after piloting

The introduction was shortened and the aims were made clearer
Gender, years in teaching university mathematics, main research interest, use of software in research, taught students, taught courses and the use of software in teaching were not changed in the final questionnaire
Items about access to software, technical support and technology training were kept in the final questionnaire
Items about how and where software is used were modified in the final questionnaire

Items about presentation software (e.g. PowerPoint), Smart Board and VLEs were included in the final questionnaire to obtain a wider view
Items about the wider contexts in which software is used (crowded classes, time, assessment, curriculum, support) were modified
Twenty-six items about attitudes towards epistemic, teaching, motivational and practical issues relating to the use of software and to the learning and teaching of mathematics at the university level were added
Items concerning beliefs about the nature of mathematics, mathematical ability and how mathematics is best learned and taught were included

The final questionnaire (see Appendix 4) addressed four themes:

The first part (questions 1 to 8) was about the participant himself or herself, and his or her experience in university teaching, including years of teaching university mathematics and statistics, area of research, use of software in research, type of students and their level of university education and type of courses they were teaching. The importance of this part lies in the fact that this study is looking at whether any of these variables have an impact in relation to the extent and rationale for usage. There proved to be a close association between the subject that a lecturer taught and his or her use of software. Subject identification was addressed in questions 3, 6 and 8, allowing the consistency of responses to be examined. A problem which the questionnaire did not fully resolve was that although lecturers taught courses associated with their specialist interests (i.e. specialists in statistics taught statistics courses and pure mathematicians taught pure mathematics courses), all lecturers also taught general courses (in particular, introductory courses such as calculus). Regarding subject identification, Q3 was the most useful question, as it asked lecturers to label their research interest and assumed that identification with a research interest served as an adequate ‘proxy’ for what the respondents taught for the most part. This assumption was supported by the interview data. However, upon reflection, it became clear there were better ways of asking about what subjects lecturers taught. For example, from the pilot questionnaire, the questions about the type of students with whom software was employed and the type of courses in which software was used should have been kept in the final questionnaire. However, it was not possible to explore the more subtle question of whether those specialising in one branch of mathematics employed technology more or less when teaching the same introductory courses taught by all lecturers.

The second part (questions 9 to 15) looked at access to ICT resources and training including access to software in mathematics departments, lecturers' participation in technology training workshops, their attitudes towards using mathematical software packages in teaching and the extent to which the participant was a user or non-user of the software in his or her teaching. This part takes us to the heart of this study and uncovers the use of the software packages, where they are used, the kinds of packages used and what is the intended purpose of use. It also tries to uncover the reasons that make some lecturers reluctant to use software in their teaching.

The third part (question 16) looked at the wider context in which mathematical software is used and explored the views of participants about various factors in a broader context that may affect the use of software packages in the teaching of mathematics in universities. These factors include: class size, departmental support and training and issues related to syllabus constraints and degrees of autonomy in teaching and learning. The last part (question 17) covered lecturers' views on the nature of mathematics, mathematics teaching and mathematical ability.

Most of the questions used a five-point Likert scale, from 'strongly disagree' to 'strongly agree', and the others used a four-point Likert scale, from 'never' to 'always'. The former was used for most items to allow respondents to express the degree of agreement or disagreement with a set of statements that measured attitudes toward some of the issues that may affect the use of mathematical software in teaching. These issues were drawn, as indicated earlier, from the review of previous research as well as from the 18 interviews that were conducted previously. An example of an item that was presented in an affirmative way is: ‘I think it is better to use software only in courses that require it’. In this item, the scale ranged from ‘strongly disagree’, which corresponded to 1, to ‘strongly agree’, which corresponded to 5, taking into consideration that the option ‘neither agree nor disagree’ was in a one-to-one correspondence with 3. Other items were presented in a negative form. An example is: ‘I don't know how to integrate software into my teaching’. Unlike the previous example, the scales in this item ranged from ‘strongly agree’ (1) to ‘strongly disagree’ (5), with the neutral point being ‘neither agree nor disagree’ (3). On the other hand, the latter (i.e. the 4-point scales) were used when the goal was not to measure the degree of agreement, but to measure the level of frequency. In such items, frequency tables of four points, including ‘never’ (1), ‘occasionally (2), ‘frequently’ (3) and ‘always’ (4), were used. An example is: ‘I use the software in my lecture room’.

Delivering the questionnaire

The questionnaire was distributed to lecturers of mathematics and statistics (170 lecturers) at four universities located in the central and eastern parts of Saudi Arabia. I could not visit the remaining four universities due to distance and time constraints. I visited only the male departments at these four universities over two rounds of visits. Both rounds took place in the spring of 2012. The first round took place during the month of March and the second took place in April of the same semester. The decision to visit and deliver the questionnaire by hand was made in order to obtain as high a response rate as possible. One could expect that the users of mathematical software packages would be more enthusiastic to participate in such a study, whereas the non-users may not be interested or might be reluctant to participate and, notwithstanding anonymity, expose their lack of ICT use. The visits were designed to address this issue. With the help and appreciated support of the department heads and some of the members of the faculty in these departments, I set up short individual meetings with lecturers for the purpose of filling in the questionnaire during office hours. I also sent the questionnaire electronically to lecturers I was unable to meet face to face; for cultural reasons, this included the female members of the faculty.

Analysing and reporting the questionnaire data

Regarding the use of SPSS software:

1. The data were entered into and stored in an SPSS file.
2. Each row in the database ('Data View' is the name used in SPSS) corresponded to one respondent. The number of rows was 151, corresponding to the total number of respondents. Each column covered one questionnaire item (e.g. gender, years of teaching university mathematics, main research interest, use of software in teaching, taught students, taught courses, and so on).
3. The items in the questionnaire were treated as nominal variables (categories such as male/female) or ordinal variables (scores recorded for items measured on Likert scales).
4. The main purposes of the questionnaire analysis were to examine respondents' attitudes towards, and experience of, using software and to study whether there were relationships (associations) between the use of software in teaching and the other variables.
5. The data were summarised using frequencies and percentages either for a single questionnaire item or, on various occasions, for groups of questionnaire items relating to the same issue (access, curriculum, assessment, time, overreliance on software, epistemic value, value for teaching, motivational value, wider environment). To explore and test the association between two categorical variables, cross-tabulations and Chi-Square tests of association were used.

The reporting of the questionnaire data was presented in three stages (pp. 182-233). In stage 1, simple descriptive statistics were used to present the overall findings. These gave the demographic background of respondents (teaching experience, subject specialisms, gender). They also showed which courses and students respondents taught. This section also illustrated the extent of software use in teaching; where software was used and for what purposes; and commonly used software. The next part reported on factors influencing the use of software. These were access, training and support, curriculum, assessment and time, confidence and competence, stance on software, the wider environment and pedagogical beliefs. Having established the importance of subject specialism in the take up of software, key factors were broken down by subject specialism and by use of software in teaching. Finally, tests of association were carried out between use of software and various variables which were identified in the first part of the survey analysis. Often, these were composite variables aggregating different questions items in order to enable high and low groups, for example, the upper quartile represented those with a more positive attitude to ICT, and the lower quartile, those with less positive attitudes.

This analysis is detailed and proved complex to carry out, but the reporting is clear and the main findings are well supported. Points for the reader to be aware of are as follows:

(a) The identification of research specialism was a proxy measure of teaching, that is, those whose main interest was statistics were likely to be timetabled to teach statistics(this was found to be a fair assumption when interviewing lecturers);

(b) The use of software in teaching was a key variable – this was checked for consistency with the other question items;

(c) Tests of association were based on a fairly low number of data items; these are not 'proofs' of causation, but rather another dataset which strengthens the argument of association between subjects specialism and take up of software; and

(d) The item on teacher belief about teaching was misinterpreted by some respondents, although 'valid' replies did provide some useful data (pp. 222-227).

Conceptualisation of the data

In the last phase of the analysis, the findings related to the interviews and survey were integrated. This was originally carried out using a framework of 'factors that encourage/discourage the use of software and more general ICT', which was foregrounded in both the literature review and survey design. This can be seen on (pages 236-259). However, as discussed in Chapter 6 this 'factors approach' came to be viewed as limited, particularly in terms of its over-deterministic perspective on the take up of ICT. I wanted to represent the findings so that the reader could develop a better idea of lecturer agency and the context in which that agency is exercised. I decided to review the findings in light of the more abstract theories of take up of ICT, as discussed in Chapter 2 (e.g. TAM, Valsiner's zones theory, activity theory). In the event, Valsiner's zone theory proved an important reference point, but I was not to know this when starting the research. It was only after I had the data in front of me and had experienced for myself the shortcomings of the factors approach that I moved onto another approach. This was a process which required viewing the data in relation the main theories in the literature review and looking for fitness for purpose. This was a more inductive approach, but it was not grounded theory. I was explicitly building on what had been put forward in the literature, even if my choice of theory and my adaption of that theory, came after the event.

3.5 Measures to ensure the trustworthiness of this research

Validity and reliability are two criteria that are used to give researchers confidence that their measurements are accurate and consistent (Field 2009). Reliability refers to the consistency or repeatability of measurements. Validity refers to whether an instrument accurately measures what it is designed to measure (as opposed to measuring something else) (Jackson 2009), and a valid conclusion is one that is accurately drawn from the data (Kvale and Brinkmann 2009). However, qualitative researchers have suggested alternate ways of ensuring the trustworthiness of research findings. For example, some of the most influential alternative criteria were suggested by Guba and Lincoln (1985). These four criteria for trustworthiness are: credibility, transferability (parallels external validity or generalizability), dependability (parallels reliability) and conformability (parallels objectivity).

Guided by Shenton (2004), I will now discuss strategies for ensuring trustworthiness in this research using these four criteria.

Credibility is similar to internal validity in quantitative research. Credibility deals with whether the research findings and report adequately represent reality as intended by the participants. To ensure the credibility of this study, first and foremost, as I mentioned previously, given my background I was very familiar with the context. During the data collection, I had prolonged engagement with the participants. In addition, 2 different methods of data collection (18 interviews and 151 surveys) were used, which yielded detailed descriptions of how and why mathematical software was used by lecturers. All of the above strengthened the credibility of the findings. It is important not to overlook the credibility (validity) problems associated with self-report measures such as surveys and semi-structured interviews. Every effort was made to maximize the conditions so that the respondents could give honest answers (e.g. questions were simple, relevant and easy to answer, leading questions were avoided and anonymity and confidentiality were ensured).

Transferability is an alternative to external validity or statistical generalizability in quantitative research. Transferability, as the name suggests, refers to whether the findings can be transferred to other contexts. My task here was to provide a solid description of the settings in which this research took place, but each reader can decide if the findings can be transferred to other contexts.

Dependability parallels reliability or consistency in quantitative research. Similar to the close tie between reliability and validity in quantitative research (reliability is a necessary but not sufficient condition for validity), Guba and Lincoln (1985) argue that the research findings cannot be credible unless they are dependable. To ensure dependability and proper research practices, I employed interviews and questionnaire as two different sources of data. Also, as demonstrated in this chapter, justification and description of the research methodology, and methods of data collection and data analysis were addressed. Internal consistency between similar items (items which measured the same issue) in the questionnaire was ensured (see Chapter 5).

Finally, confirmability deals with the objectivity of the research findings. It refers to the extent to which the conclusions are logically based on the gathered data and not based on the preferences of the researcher. While recognizing that there were shortcomings in the methods employed and the potential effect of the lack of formal observation, confirmability was established in this research through the use of two different sources of data to enhance triangulation and reduce my own bias. Also, in the interview and survey analyses chapters (Chapter 4 and Chapter 5), I provide examples of the raw interview data and frequency tables of the survey respondents to ensure that the analysis and interpretation were grounded in the data.

3.6 Ethical issues

This research was undertaken in a manner that respected the ethical principles for social sciences research. Before conducting the interviews I submitted an ethical review report to the Institute of Education at Warwick University. During the interviews, every interviewee was asked for their informed consent to participate, thus ensuring the voluntary nature of their participation and respecting their confidentiality and right to withdraw from the study at any time without giving any reason. During transcription and reporting, confidentiality was ensured by using the symbols A and B to represent the two departments of mathematics, and the numbers 1 to 9 to represent interviewees (e.g. 'A3' refers to the third lecturer in the Department of Mathematics 'A', while 'B9' refers to the ninth lecturer in

Department of Mathematics ‘B’ and so on). For the questionnaire part of the study, the respondents were informed on the first page of the questionnaire that all replies would be treated as confident.

Chapter 4 Interview Analysis

4.1 Introduction

In this chapter, I present an analysis of the interview data with 18 lecturers from various branches of mathematics at two major universities in Saudi Arabia. First, I discuss the two universities and the general context in which these interviews were conducted. Then I present an overview of the undergraduate mathematics programs at these two universities, before moving on to discuss the findings of the interview data. These are discussed under three main themes: use of software, rationale for using software and rationale for not using software.

As discussed in Chapter 3, during each university visit I conducted interviews with nine mathematics and statistics lecturers. They were chosen as they represented all of the main research interests in mathematics. Table 17 shows the distribution of interviewees at each university according to their subject specialisms within mathematics.

Table 17: The interviewees and their specialisms

Subject specialism	University (A)	University (B)
Pure Mathematics	Two lecturers (A1, A2)	Two lecturers (B1, B2)
Applied Mathematics	One lecturer (A3)	Two lecturers (B3, B4)
Computational Mathematics	Two lecturers (A4, A5)	Two lecturers (B5, B6)
Statistics	Four lecturers (A6, A7, A8, A9)	Three lecturers (B7, B8, B9)

Before going into details of what the lecturers said about their use of mathematical software in teaching, and the reasons for the use or non-use of software, I should start by giving an overview of the use of software in the two departments, as well as providing a simplified description of the two mathematics departments covered by the interviews.

4.2 The Two Universities and the Context

Regarding the ICT infrastructures, all of the classrooms at both universities were smart classrooms. They were all equipped with PC monitors and an overhead multimedia projector, and an Internet connection was available everywhere on the two campuses for all staff and students. LMS were available and used by faculty members and students at both universities. The Blackboard (Bb) LMS system was used at both universities. At the time when the interviews were conducted (2011), university (A) was in its first year of usage of Bb, while university (B) had been using Bb for years.

Software was used as a requirement in two types of courses: computational mathematics and statistical courses. In other courses, software was sometimes used in a supplementary way by some lecturers, particularly at university B. Out of the 18 lecturers interviewed, 2 were enthusiasts in the use of software in teaching: one specialized in computational mathematics at university (A), and the other worked at university (B) and his area of specialization was applied mathematics (fluid mechanics). Both lecturers used software heavily in all of the courses they taught. On the other hand, two lecturers were critical of the use of software, even if they had to use it heavily in the courses they taught (one taught statistics at university (A) and the other specialized in computational mathematics at university (B)).

An overview of undergraduate mathematics

Undergraduate mathematics programs at both universities consist of basics courses in the three main branches of modern mathematics: pure mathematics, applied mathematics and computational mathematics. In both universities, the first two years in the bachelor's degree program in mathematics consist of general courses. These courses include calculus (e.g. differentiations, integrations, vector calculus and calculus in three dimensions), linear algebra, abstract algebra and ordinary differential equations (ODE). After that, the last year or two of the bachelor's degree program consists of more specialized and advanced courses. These courses include numerical analysis, real and complex analysis, group and Galois theories, ring theory, field theory, topology and partial differential equations (PDE). Computational mathematics, which includes courses such as numerical analysis, is the branch of mathematics that relies heavily on computations and programming, and hence the use of software.

Mathematics courses generally involve two kinds of activities: theoretical activities and practical activities. Perhaps for this reason, most mathematical courses in the two universities comprised main classes in which students studied the theoretical foundations of the course, and exercises (or tutorial) sessions in which students were trained to practice what they have learned in the main classes in solving problems.

The Department of Mathematics at university (A)

The Department of Mathematics at university (A) is the oldest and largest mathematics department in the country, and is located within the largest university not only in Saudi Arabia but also in all the countries of the Gulf Cooperation Council. This Department of Mathematics includes more than 80 lecturers from various branches of mathematics. At the time when this research was conducted, the department had 3 computer laboratories containing more than 70 PCs. All lecture halls and classrooms were equipped with a blackboard (or whiteboard), a projector, an e-podium and an interactive whiteboard (IWB). The university had subscribed to the Bb LMS since January of 2011. This department provides undergraduate and graduate programs in various areas of mathematical sciences, including pure, applied and computational mathematics. It also provides service courses to most colleges at the university such as engineering, science, management and computer science from calculus to more advanced courses. Statistics at university (A) was initially a sub-major in the Department of Mathematics before being established as an independent department within the College of Sciences. The Department of Statistics offers bachelors and master's degrees in statistics. It also provides special service courses for students in most colleges, for example: engineering, computer science, medicine, pharmacy, dentistry and others.

Two computational mathematics courses require the use of software. The first is numerical analysis, which is a requirement for all students majoring in mathematics and engineering. As a prerequisite, it is a necessary requirement to pass another course: computational mathematics. Computational mathematics focuses on learning a variety of mathematical topics and their applications using major mathematical software such as Maple, MATLAB, Mathematica and Scientific Workplace. In addition, passing a course in computer science, namely computer skills, is a requirement for all students of the Departments of Mathematics and Statistics. In this course, students learn the basic principles of one programming language (mostly Visual Basic).

Regarding assessment at this Department of Mathematics, there was no use of mathematical software except for homework projects in numerical analysis courses (about 10% of the total marks). All other examinations set by this department were written examinations with no use of software. A1 stated that in some calculus courses, students were allowed to use basic calculators (i.e. hand-held calculators without programming capabilities) during examinations.

The Deanship of E-Learning and Distance Learning (DE&DL) at university (A) trains and gives technical assistance to lecturers in the use of ICT. According to its website, The DE&DL 'provide the environment and appropriate training to enable faculty members carry out their duties relating to the assessment of students and monitor the results and deal actively with the learning management system LMS in the university; and to create incentives for those who excel among the faculty members in the use of e-learning'.

The Department of Mathematics at university (B)

In contrast to the previous university, statistics and mathematics are not two separate departments, but are grouped under the name 'Department of Mathematics and Statistics'. The Department of Mathematics and Statistics is located within a university that specializes in sciences and engineering. The university is highly selective and only accepts the best students using strict admission standards to ensure the quality of the chosen students. As such, it is considered one of the best universities in Saudi Arabia in terms of providing the highest degree of excellence in its programs. The Department of Mathematics and Statistics is one of the largest departments in the university, with about 65 lecturers from various areas of mathematics and statistics. This department, in addition to offering various undergraduate and graduate studies in mathematics and statistics, provides service courses for various departments.

The Information Technology Centre runs many of the computer labs in many of the university buildings and colleges, one of which is in the Department of Mathematics and Statistics. Several mathematical and statistical software packages are available (e.g. MATLAB, Maple, Mathematica, SPSS, Minitab and STATISTICA). The university has had licences for Web CT and Bb as LMS for several years. Internet connections are available everywhere on campus. All lecture halls and classrooms are equipped with PCs, multimedia projectors and IWBs. With respect to the assessment process, in mathematics courses, an online homework system is used in calculus courses; other than that, all examinations are written.

4.3 The findings

The findings are organized around three main categories: use of software, rationale for using software and rationale for not using software.

4.3.1 Use of software

At university (A), despite the availability of ICT facilities including mathematical software, mathematics lecturers used software only in courses that required its use, of which there were only two courses: numerical analysis and computational mathematics. The only exception was one faculty member, who used e-learning, including the use of mathematical software, in all of his courses. His specialization was computational mathematics. He explained that every week the students had a forum; self-assessment; links to the topic of the week and to various questions; and a journal, where each student could write whatever they wanted to write. He said that his goal was for students to have fun learning. He acknowledged that the students still preferred the traditional way of teaching, and he realized that change towards learning that depends on ICT may need more time. He asserted that students should be allowed to learn mathematics within a 'smart' learning environment, and he stressed that the use of software would be a key factor within that environment to allow students' minds to open up and see the beauty of mathematics.

Unlike the situation at university (A), mathematical software packages (e.g. Mathematica, Maple, Minitab, MATLAB, Excel), and programming languages (e.g. Fortran, C++) were used more frequently in teaching undergraduate mathematics courses at university (B). Software packages were used as a mathematical aid in some of the lower-level courses such as calculus and algebra, but were not an essential part of these courses. Some lecturers reported using software during their presentations to illustrate some of the topics. For example, B6 emphasized that he used software only as a supplementary part and as a teaching tool. He added that the use of software was not specified in the course syllabus, with the exception of courses that required it, such as statistics and numerical analysis courses. He mentioned that taking a programming language course (mostly C++ or Fortran) was a core requirement for all students at the university. B1 stated that he used the package Mathcad in the teaching of a pre-calculus course. Although more lecturers may have used software in teaching in this department compared to the former department, it must be stressed that the use of chalk and board was still the dominant practice even in this department. As B6 asserted, one should use software as an aid, but not as a substitute to the traditional methods of teaching, particularly in a subject like mathematics.

There were degrees of flexibility and autonomy when it came to using software packages in the teaching of mathematics at both universities. Although a course description would specify all the topics and textbooks in each course, it was actually left to the lecturer to choose what an appropriate teaching tool, including software packages was. This was true even when teaching courses that required the use of software packages. For example, B5, who was a lecture of numerical analysis, used Excel, and not MATLAB, C + +, Fortran, or any other software that is commonly used in such a course. When asked about the reason for choosing Excel and not MATLAB or other software, he said that the reason was that by using Excel the user would be able to have complete control over the entire process from A to Z. He stressed that the aim of using software should not be a process of 'pressing buttons' without knowing what really happened inside the device, which makes many mathematicians, in his view, reluctant to use the software. He added that one should be careful when it comes to the use of software, especially at the stage of university mathematics, which should be the stage of building students' mathematical backgrounds. In his opinion, the initial stages of undergraduate study are the construction phase of the students' backgrounds, and should not be impeded by the use of software packages. I will come back to this point later in this analysis.

The use of software is essential in statistical courses. All of the statisticians in the sample from university (A) emphasized that they used statistical packages in all statistical courses they were teaching. They stressed that in statistics, after collecting numerical data, the objective is to analyse the data using software, then one can make decisions based on that analysis. A6 stressed that because they were dealing with data they were probably the biggest users of software. He added that in mathematics, one could teach the majority of courses without the use of software, whereas most statistical courses are heavily dependent on data analysis, in which the use of software is essential.

Because of the large number of students at university (A), it was difficult to accommodate them all with what was available in the laboratories. The statisticians at this university stated that students from outside the Department of Statistics were not offered statistical laboratories. In other words, statistical lecturers at university (A) used statistical packages during their presentations. However, students were not able to use statistical packages because the university did not provide them with laboratory times in such courses. The only exception was those students who were majoring in statistics.

As was the case at university (A), statistical lecturers at university (B) used statistical software packages (e.g. STATISTICA, Minitab and SAS) heavily during their teaching. The only obvious difference between the two departments was that all students who enrolled in statistical courses at university (B) were offered statistical laboratory sessions, whether these courses were offered to statistics students or to non-statistics students. This was perhaps because the number of students at this university was much smaller than at university (A). B8 stressed that statistical analysis is an integral part of coursework in statistical courses; therefore, statistical courses were taught mostly in computer labs, where every student would be able to do their coursework and assignments using the software.

Types of software used

In term of the software packages used when teaching the undergraduate mathematics courses, Mathematica was the most widely used mathematical package with 25 references from 12 participants (out of 18) mentioning that they were using it in their lectures (see Table 18). MATLAB followed closely with 20 references from 11 different participants. The third-most frequently used mathematical software was Maple, which was mentioned in 13 different references by 10 participants in the sample.

These three were, by far, the most frequently utilized mathematical software. Less-common mathematical software included Scientific WorkPlace, Excel, GeoGebra and Mathcad. More general software such as C, C++, Fortran and Visual Basic were also mentioned, but less frequently. Wolfram Alpha, an on-line environment that uses Mathematica, was mentioned by one participant who used e-learning in all of his classes. He created 'cyber classes' or webpages with links to on-line resources for use beyond the lesson: '… in the front page of the cyber class there is a link to Wolfram Alpha… it's beautiful for them to check anything they want. For example in integration they go to Wolfram Alpha if they want to see some questions they cannot find the answer for or whatever. They just write integral or 'INT' and they see immediately the answer with graphical solution and all sorts of things. So these kinds of software are beautiful for helping our students…so what I always hope is to encourage my students and for that I use all the facilities available. For example, Excel is a lovely environment and it is available for all students. MATLAB of course is used heavily…I prefer Maple sometimes over Mathematica' (A4).

All of the statisticians in the sample (seven lecturers) used software. This is not surprising as statistics depends heavily on the analysis of large data sets. All the seven statisticians always used statistical packages in teaching. Minitab was the most commonly used software, used by all of the statisticians in the sample, with 13 references. SPSS (10 references), STATISTICA (7 references) and SAS (5 references) were also commonly used (see Table18).

Table 18: Software packages used in teaching by interviewees

Software	Number of references	Number of sources
MATHEMATICA	25	12
MATLAB	20	11
MAPLE	13	10
SCIENTIFIC WORKPLACE	3	3
GEOGEBRA	1	1
MATHCAD	1	1
EXCEL	3	2
MINITAB	13	7
SPSS	10	7
SAS	5	4
STATISTICA	7	4
C++	2	1
C	1	1
FORTRAN	2	2
VISUAL BASIC	1	1
WOLFRAM ALPHA	1	1

The courses in which software was used

Regarding the courses in which software was used, as shown in Table 19, computational mathematics courses, which include numerical analysis, were the most frequent mathematical courses in which software packages were used with 19 references from 8 participants. Calculus (either 2D or 3D) followed that closely with 15 references from 9 sources. These two mathematical courses were by far the most reported courses in which software was used. This is not surprising as computational mathematics by nature depends entirely on computation and programming. Calculus courses are probably one of the most offered university courses that are compulsory and a prerequisite for many courses at most universities.

Perhaps one of the most predictable results in this study was that statistical courses were the top of all of the courses in which software was used. There were 14 references in which 8 different sources mentioned that they taught statistical courses that involved the use of software. Examples of such courses included: statistics for engineering (3 references), statistics for management students (3 references), non-parametric statistics (2 references) and data and analysis of experiments (1 reference). In addition, software was used in a variety of other mathematical courses, such as: differential equations (5 references), linear algebra (2 references), abstract algebra (2 references) and applied mathematics (3 references).

Table 19: Example of courses in which software was used

Course	Number of references	Number of sources
Calculus	15	9
Pre-calculus	1	1
Calculus in 3D	2	2
Computational mathematics	19	8
Differential equations	5	4
Linear algebra	2	2
Abstract algebra	2	2
Applied mathematics	3	2
Statistics	14	8
Number theory	1	1
Analysis	1	1
Linear programing	1	1

Examples of taught topics in which software was used

Regarding examples of taught topics in which software was used, a wide range of examples of statistical and mathematical topics were mentioned by the participants. For instance, in calculus courses, some interviewees reported that they used Mathematica or Maple to integrate, differentiate, find the limit of or graph a particular function. In the more advanced 3D calculus, some of the participants stated that they used software to help students visualize service convolution and to find the volume of a function. In numerical analysis, some participants said that they used MATLAB and Excel in topics such as matrices computations, to produce iterations and to write codes when applying different methods to find the roots of equations. In differential equations (e.g. ODE and PDE), some of the interviewed lecturers reported using software packages to solve differential equations, and once the solutions were found, to plot the resulting functions. In other mathematical courses, further examples mentioned by the participants included:

- To expand a function in a Fourier series in a Fourier analysis course
- To plot a vector field and to animate a tangent vector in PDE
- To implement the Gauss-Jordan method to solve a system of linear equations in linear algebra
- To calculate the centre, centralizer, normalizer and normal subgroup in abstract algebra
- To visualize and rotate cross sections of cylinders to get an estimate of the volume in geometry
- To demonstrate the areas of a triple integral in 3D calculus
- To find the mean, median, standard deviation and variance of particular data
- To implement regressions of some observations in statistics.

Some participants mentioned situations that software could not handle well. For example, B6 pointed out that when handling topics such as singularities or ‘when things get closer to zero’, many of these software packages could not handle such problems correctly. Therefore, students were warned not to rely totally on the technology to come up with solutions in such cases.

Where software was used

Regarding the teaching settings in which software was used, there were considerable differences between mathematicians and statisticians. Computer laboratories were used mostly by statistics lecturers, and not by mathematics lecturers. However, statisticians used statistical packages in their lectures using the multimedia projectors as well as in the computer labs. In addition, students of statistics were required to do their coursework using software in the laboratory. In mathematical courses in which the use of software is required (i.e. in numerical analysis and computation mathematics), the participants stated that usually one or two lectures were allocated to allow the lecturers to explain to the students the basic commands of the chosen package, and then students were advised to use online help to get acquainted with such software. In such courses, the lecturer introduced the software in the context of teaching (usually using presentation software) then students were asked to do homework assignments that involved the use of software. In terms of assessment, statistics students were assessed in the laboratory because some of the questions required using statistical packages, while mathematics students were assessed through written examinations with no use of software. In computational mathematics courses though, there were homework assignments that required the use of software for which about 10% of the total marks were allocated (e.g. A5, B6).

Learning management systems

Using LMS were voluntary and mainly used by lecturers to make general announcements, to connect with students via e-mail or to post course-related materials. B4 stated that he used Bb in three ways: making general announcements to students, sending e-mails to groups or individual students and posting lecture notes, assignments, exams, quizzes, etc. 'Most of our faculty members have a website and they post various materials for their courses, for example, exams, lecture notes, syllabus for each of their courses' (A1). There were no online courses offered through the LMS. As A1 pointed out, it was not an easy task to build a course online because it required team work or at least someone who was a mathematician and an ICT expert at the same time. A4 indicated that there was a process of change. For example, a new committee had been set up to design e-courses. A4 mentioned that he also worked with the National Centre of E-Learning and Distance Learning to develop e-courses such as calculus and numerical analysis to be accessed by lecturers and students in all universities in Saudi Arabia. A4, who was a self-motivated lecturer, indicated that he had his own online courses in the LMS Moodle before his university subscribed to Bb. The main objective of using LMS according to A4 was 'just to be connected with your students and to make a community of learning'.

At university (B), an online homework system for calculus had been developed. B3 stressed that he had found many benefits in using the e-assessment system. However, one drawback he had witnessed was that lecturers did not see the details of students' working. B3 added he usually asked his students to attach PDF files of their work in order to see how they had arrived at their answers. B3 claimed the online homework system was generally preferred over traditional paper-based examinations. Colleagues viewed it as an effective and efficient way to support learning. B3 stressed that the use of e-assessment reduced the chances of cheating and provided the students with opportunities to learn from their mistakes.

Now that we have seen how software packages were used for teaching by lecturers from different branches in the mathematics and statistics departments at the two universities, we turn to explore the motivating factors, and also the impeding factors that hindered the use of software.

4.3.2 Rationale for the use of software

The motivating factors will be divided into two parts: factors related to a belief about the value of software for learning, teaching and motivation and contextual factors. First I will discuss factors related to a belief about the value of software for learning, teaching and motivation.

Speed and automatic calculation

Interviewees gave a wide range of examples that suggested that software could enable lecturers to calculate things very quickly, or to produce displays that would be impossible or very difficult to do otherwise. This saved them a lot of time, and re-focused students' attention away from complicated calculations that would otherwise take most of the time for the lecture; this was especially important when performing such calculations was not the direct objective of the lecture. B3 pointed out that it was a waste of time every time a lecturer was faced with a function that needed to be expanded in a Fourier series, for example, to do that calculation manually. In such a situation, it may be helpful to use the software. B3 asserted that he only used software for routine problems or calculations that would take a long time, or when such calculations were impossible to do by hand. He gave an example of trying to plot a complicated graph in three dimensional spaces and how it was very difficult to draw such a graph properly without spending most of the lecture time trying to draw a decent graph. B2 questioned the value of spending a long time in solving every single problem in, say, integration or differentiation manually if the students had understood the concepts involved. He felt that software should be used to obtain ‘quick answers’ and that these answers can be used to discuss underlying conceptual issues.

Software assists visualization

Visualization was the second main purpose of the use software packages in the teaching of mathematics. For respondents, visualization meant that the images and geometric shapes that are produced by the software can help students to see (or visualize) geometric shapes, especially when things get complicated in three dimensions spaces. Visualizing mathematical objects can be static or animated. For example, as B6 put it: 'visualization of the functions, especially when you get to the topics of solids and convolutions, it is much easier with Mathematica to get students visualizes the whole solid and how to find the volume'. A2 explained that with software, lecturers can actually display the 3D shape from various angles and rotate it, turn it upside down and even select parts of it and zoom in to highlight that part, and so on. Without using software as a tool to assist visualization, A2 stated that many students would not have such opportunities to visualize 3D mathematical objects. He stressed that using software to assist visualization was a great blessing to the teaching community that helps to transfer knowledge more effectively. B2 did not hide his criticism of those lecturers who were totally opposed to the use of the software; he stated: 'instead of just doing the calculations on the board or graphing them or doing the calculation without really seeing the object we are calculating, it doesn't make any sense to me'. A4 stated that he used GeoGebra specifically because it helped the students to visualize geometric objects. Then he criticized mathematicians who focus more on an algebraic approach and neglect the visual side of mathematics. He said he was 'amazed' to see in a course like calculus, which deals with 'functions', students could not visualize even a 'constant function'. He did not blame this only on the higher education curriculum but he felt this went back to teaching in school. He mentioned the movement known as 'calculus reform' which has emphasized the use of the senses to 'visualize' mathematical functions and let students 'see' the functions not just represent them algebraically. He stressed that students should be given a learning environment which afforded visualizing mathematical functions. In such an environment, software should be an easily accessible object.

Speed automation and assisting visualization can both help to acquire the third objective, which was to make things clearer to students so they can understand and absorb things better, as we shall see below.

Software makes things clearer

As was indicated previously, mathematics involves procedural and intellectual activities. Clarifying things for students is a main concern and a desired goal for most teachers in mathematics courses. This goal can be achieved with the use software packages in several respects.

Some of the participants made it clear that the goal of making things clearer could be achieved by focusing more on understanding concepts rather than focusing too much on procedural calculation, which itself was not the direct goal of the lecture. This in turn would also save energy for students, allowing them to focus on more important things that were the immediate objectives of the lecture. A2 stated: ‘why to consume students’ energy if I am doing a work for an hour and that work can be done, say, within one minute. So why do I keep working for another 59 minutes? So it saved time and left him time to go into higher thinking activities’. In the same context, A4 mentioned that there was no need to waste precious time in the lecture performing boring procedural calculations, especially if they were not the immediate objectives of the lecture. Then he gave the following analogy of who would do that: ‘instead of just spending the time in what was known in England as ‘donkey work’… we have to move them away from that’.

Software could also aid the lecturer in representing mathematical ideas in multiple ways within the very limited time of the lecture (i.e. multiple representations), which could make things clearer for different types of learners or as A2 pointed out: 'one can use the software to demonstrate the same object in different ways'.

Some participants emphasized that the use of software would likely lead to understanding not only the use of software itself but also understanding the theoretical basis behind such use. Consequently, it could lead to understanding the underlying mathematical topics that involved such usage. In this regard, A2 stressed that if students used software, it would not only speed up their computations, but they would also develop understanding of the theory behind such use. Making things clearer was a desirable goal, even in a subject like statistics where the use of software is necessary, or as A8 stressed, in statistics, students' ideas are strengthened by data.

In addition, some asserted that they noticed that the use of software made a difference for some of their students. In that respect, B3 stated: 'basically you want them to learn something and you think some of them have otherwise will not learn with the chalk and talk'. In the same context, A1 stated: 'I think the use of software could be very helpful. It could solve some of traditional problems that mathematicians face in trying to explain the materials to the students'.

Before moving on to the next point, it should be noted that one of the participants expressed disappointment and surprise at what he had observed by his fellow lecturers of mathematics regarding their reluctance to use software in their teaching, even though computers were created by mathematicians. In this respect, A4 said: 'Why? Something wrong here; software was created by mathematics the queen of sciences, so it is time for mathematics the queen of science to benefit from that, and so people can use this technology in seeing her beauty'.

Software engages students and makes them interested

Engaging, involving and making students interested, or trying to encourage them to have fun when learning mathematics, were all seen as part of the motivational value of the software mentioned by some of in this study. A1 suggested that some students may find 'traditional' ('chalk and talk') lectures boring; software could appeal to these students. A4 described how he tried to give his students the attitude of 'having fun' with mathematics in the 'cyber-classes' he designed for his students, which he used in Moodle for all of his courses. He asserted that his students seemed to enjoy the attitude of learning mathematics with 'fun'. They were interacting with each other and he was sitting with them virtually as one of them watching and observing like 'a guide on the side' trying to minimize his interference. B2 was another lecturer at the other university who described the happiness he saw on his students' faces whenever he used Maple to rotate some of the surfaces and to find an estimate of the volume of some geometric shapes, stressing that students' interaction has actually risen since he started using this package. A2 emphasised that mathematics lecturers in particular should use technology to their advantage to help their students focus their attention on the most important points of lectures. He stated: 'when teaching a highly intellectual discipline such as mathematics; you can put so many things which can make the students happy'. For example, he stated that lecturers could attract students' attention by preparing slides with different fonts and colours which helped students to draw a distinction between theorems, corollaries, lemmas, definitions, examples, remarks and proofs. He felt that this could positively affect lecturers' presence and performance and help in making very well presented lectures.

Software saves lecturers' time in their teaching

Some participants stated that they used software in order to make teaching more efficient with respect to saving time for performing other tasks rather than spending time computing routine calculations. For example, B3 asserted that it was a waste of time if every time he expanded a function in a Fourier series he had to do it manually in front of his students. Thus, in such a situation, he found it useful to let the software compute the expansion in order to save him time for other, probably more urgent, tasks. A2 mentioned an example of his use of PowerPoint presentations as a tool to organize his thoughts and to save time in lectures, especially when he taught early-stage courses at the undergraduate level where students were often slower in their writing. One of the benefits of using software when teaching mathematics that was mentioned by A2 was that the use of software saves lecturers from misleading students because lecturers might make errors unintentionally when they write something randomly on the board.

Vocational and professional preparation

Two interviewed lecturers reported that they felt they were obligated, as part of being faithful to their career, to expose their students to the available technology as they might need to use it later in life. B2 stressed the point that every graduate of mathematics must receive minimal exposure to at least one of the major mathematical software packages during their university studies. A2 shared the same view and stated that 'going computational has been the trend in the world nowadays, and all the workforce needs are demanding graduates who are knowledgeable, particularly in dealing with technology and mathematics graduates should be in the forefront when it comes to dealing with technology'.

After discussing the factors that encouraged the use of software in the teaching of undergraduate mathematics and statistics courses from a perspective of lecturers' beliefs about the value of software for learning, teaching and motivation, I will look now at the contextual factors that encouraged the use of software.

Easy access to ICT

At both universities covered by this study, there was easy access to ICT facilities. At both campuses, Internet connections were available everywhere; all classes and labs were equipped with IWBs, multimedia projectors and Internet connections. Both departments had fully equipped self-learning labs. As far as mathematical software packages are concerned, one mathematics department had already subscribed to major mathematical software packages such as MATLAB, Mathematica, Maple and Mathcad; whereas the other department was in the process of subscribing to these packages. Regarding statistical packages, both statistics departments had full access to major statistical packages such as SAS, Minitab, SPSS and STATISTICA. Both campuses had licenses for the Bb LMS.

It is worth noting here that A4, who was one of the enthusiasts who believed in the importance of using software in teaching mathematics, had overcome the difficulties he faced with respect to his university not having licenses for major mathematical software packages such as Mathematica and Maple, by using free Web-based software that did not require a license, such as GeoGebra and Wolfram Alpha. A4 stated: 'now we are in different stage completely we are. Everything is ready, everything is beautiful. In the old times, I couldn't find labs for my students. Nowadays, each student has his own laptop and wireless connection in any lecture hall. They can sit in the coffee room and do their work, so it is a different environment; the environment is beautiful nowadays'.

The university encouraged the use of ICT

Lecturers thought that universities at managerial level were pushing for e-learning. Each had a deanship of e-learning, which gave trainings and provided technical support for lecturers on the effective use of ICT to achieve learning objectives. The academic freedom that university lecturers enjoyed gave them the choice to teach either with or without the use of software. In this regard, A4 stated: 'as far as policy, here we have the chancellor, we have the deanship, the dean in our college, and everyone is trying their best to implement it. But you cannot force people'.

In some courses, it is very applicable or even required to use software

As indicated previously, the use of software was not required nor even strongly recommended in all mathematical courses. According to the participants (e.g. A1, B6), the need to use software in mathematical courses varied depending on the nature of the course. For example, in some mathematical courses, especially in pure mathematics courses based on theory and studying proofs, it was very difficult to use software, except for communication purposes. Other than that, it was left to the lecturer to decide whether or not to use software. However, there were some courses in which the use of software was probably more urgent than in others. For example, the need to use software in a course such as calculus in three-dimensional spaces was perhaps more pressing than in calculus in only one dimension. This is because in such a course, students need to integrate three times, which will produce solid-shaped functions. Therefore, lecturers may need to use software to let their students visualize such complicated functions.

As B6 described, the general practice was that some lecturers used software packages as a supplement to help students understand or illustrate some of the topics. However he stressed that in computational mathematics courses, students were required to use software to compute algorithms, or to write their own codes. B5 pointed out that he could not do numerical analysis without using software, because as he put it, 'it takes forever if you do not use software'. Therefore, in such courses, it was specified in the syllabus that lecturers must use software, especially software with programming capabilities, such as Mathematica, MATLAB or any general programming languages such as C++ or Fortran. In addition, all statistical courses were by nature required to use statistical software to perform data analysis; as B9 stated: 'you cannot do statistics course without software. We specified in the syllabus you need to use that package'. B1 believed that the use of software was more appropriate when teaching a course for non-specialist mathematics (e.g. engineering students) because as he put it, 'engineering students just need to know the skills; they do not need to learn 'epsilon-delta' and all these details. For mathematics students though it is different philosophy, here we want to strengthen our students' background in the thinking of mathematics not just on doing mathematics'.

It is quite easy to use mathematical software packages

The interviewed lecturers who used software packages stressed unanimously that mathematical packages, particularly symbolic manipulators such as Maple and Mathematica, were easy to learn and use compared to more 'traditional' programming languages such as Fortran or C++. They stressed that the more traditional programming languages were not seen by their students as user friendly since, in such languages, syntaxes and writing programs were sometimes very complicated. In mathematical software packages, however, to plot functions or to perform mathematical calculations, one mostly uses ready-made, built-in functions or very easy syntaxes.

After discussing the rationale for using software in teaching, I will move on to discuss the other side, which deals with the rationale for not using mathematical software packages in the teaching of mathematics at the university level.

4.3.3 Rationale for not using software

Now I will discuss the rationale for not using software in terms of doubts about the value of software and contextual problems. Doubts about the value of software will be discussed first.

Presentations should be rough and ready (use of chalk)

Some interviewees explained that when it came to teaching mathematics, it was more natural to use 'chalk and board' as this supported a more fluid and free flowing style of teaching and made it easier for the students to interact and reflect. A2 made it clear that he firmly believed that when it came to teaching mathematics, it was inevitable and unavoidable to use the board, whether a blackboard or a whiteboard, a traditional board or electronic board. He asserted that it was possible in any other subject other than mathematics to replace the board with any other means, such as PowerPoint presentations, but when dealing with mathematical topics, the commentary and explanations on the board were not optional, but rather necessary. He explained when writing notes on the board to start from some logical base and then keep deducing new ideas from old ones, and then exemplifying things. B5 stressed the importance of the time spent writing down the small details of mathematical problems instead of posting them using a PowerPoint presentation. He emphasized that from his experience, when he wanted to save time by posting the problem, thinking that the students had understood what the problem was asking them to do, when they started working on the solution he realised that they had not yet absorbed what the problem was saying and what they were supposed to do to start solving it. However, they had absorbed what the requirements of the problem were when the lecturer wrote down the problem on the board and discussed with the students what was required. He stressed that this amount of time was essential to help the students absorb what the problem was about. He concluded that when lecturers try to save time by using a PowerPoint presentation, they will lose the students.

It is all a 'black box'—overreliance on it

Some of the interviewees expressed their concerns that if students were allowed to use software packages at the university level, which involves learning basic concepts in order to establish students' mathematical backgrounds, this might be counterproductive and harmful, especially at this foundational stage of their journey to learning mathematics. The idea of using software packages as a black box, providing answers without or with little understanding of the mathematical ideas behind the use of the software, was a concern mentioned by more than one of the mathematicians interviewed for this study. B5 questioned the value of using these more advanced software packages such as Mathematica and Matlab when learning mathematics. He stated that in these packages, one statement could do everything and the learner might not know the inner workings of the software and he or she could not easily control it. B1, who was a mathematics lecturer with a managerial responsibility in the department of mathematics B, emphasized this particular point of view, which was deemed to have great importance in his view, by saying: ‘later they can just go and forget all about calculus and since they have the packages they can do whatever they like by it, but for now you want to strengthen their background on the thinking of mathematics, not just doing mathematics’. B4 did not agree with such a concern, saying: ‘I don’t think so because if you look at all the top universities everywhere in the world from Cambridge to Harvard, it is fully interactive you have software packages. Even to use software packages you have to understand you cannot just press button; when you use a software package you have to understand what is you are doing, the nature of the problem, generate a mathematical model and then you have to adjust the parameters to know how to simulate what you want. So mathematical understanding is implied in your use of software—you cannot avoid that’. B4 added another point in this regard, stressing that in the case of over-reliance on technology or if a user did not know how to perform the calculations manually, in fact very quickly he or she will likely find it very difficult to do so using technology or he or she will inevitably face difficulty in subsequent courses.

A4 stressed the distinction between the two approaches in this regard. The first approach, which was ‘bad’ and ‘distractive by all means’, was the use of technology as a black box by pressing on a button to get the result without any knowledge of how the inner functions were working or what was happening inside the ‘box’. The second approach was the glass-box approach, which could be described as learning through building. In such an approach, students were trained to build the icon that they pressed. He stressed that unless we turn to construction, and to seeing how things work, or at least thinking about how they work. He stressed a very important point: lecturers should be careful not to use the black-box approach unless they carefully pass through the first stage of the glass-box approach. He gave an example of a package such as MATLAB. It should not be used in a course for matrices laboratory courses while students are learning the procedural skills of how to do matrices calculations. There, they must not allowed to use it as a black box, but they should use it to build little programs in MATLAB, then in a linear algebra course, for example, which is an application of that, they should be allowed to use it as a black box because students then know the Gaussian elimination process so they should be allowed to use it and use the lesson time on higher-thought activities. A5 shared the same concerns about the black use of software; he stated that he always warned his students not to resort to using ready-made functions in the software before having full knowledge of the theory behind such functions. For that reason, he always asked his students to write a short programme when solving any problem using the software. In this way, the students would develop an understanding of the theory and the rationale for carrying out the procedures. Perhaps this was why an experienced lecturer interviewed for this study chose to teach numerical analysis, a course which relies entirely on the use of software, using Excel instead of MATLAB or Fortran. B1 asserted that for this reason, and in order to strengthen students’ abilities in basic mathematics, the use of calculators, including graphic calculators, was not allowed in any of the calculus courses.

Learning requires effort

There was a view that at the undergraduate level, students need to make additional efforts and spend considerable time to learn mathematics from first principles before resorting to ‘ready-made’ functions. A7 and B5 shared the view that taking the hard way to learning is the right way, and will produce thoughtful and skilled mathematical minds. They saw learning as a daunting process, at the start of which the learner was probably 'weak', and as time passes his or her mathematical abilities and skills become stronger. They believed that over-reliance on technology, especially in the establishing stage of learners' skills, was resorting to the easy way out, which would weaken the basic mathematical skills of learners and would produce 'lazy' graduates. B5, who used software extensively in his numerical analysis course, questioned the value of resorting to software to assist students in visualizing mathematical objects at the undergraduate level and stressed that when he was a student, he was initially weak in visualization but became a good 'visualizer' after years of sustained effort.

Now that I have discussed doubts about the value of software, I will explain some of the contextual problems that prevented some lecturers from using software when teaching mathematics courses.

In some courses software is not applicable as they are about theory, not techniques

'The course nature does not require the use of software' was the top reasons given by some of the interviewees as to why they did not use mathematical software while teaching. They stressed that they simply could not or did not know how to use these packages when the goal, of course, is the production of proofs. Some examples of such courses included: advanced calculus, real and complex analysis, number theory and group and Galois theories. B5 pointed out that, unlike any other subject, teaching undergraduate mathematics aims to build students' mathematical background, and therefore they must rely heavily on the chalk and board, and limit the use of software as much as possible as it may be counterproductive at this stage. He added that although his specialty is computational mathematics, he shared this view with the mainstream mathematicians. He went on to say: 'I have not seen any book which would implement, say, Mathematica in learning advanced calculus because in such courses your concentration is on producing proofs where Mathematica doesn't do that'. B3, who used Mathematica heavily in all of his calculus and differential equations classes, asserted that in some area of mathematics, it was very difficult to integrate technology. For example, it was possible and even desirable to use software when teaching a calculus course for engineering students because the engineering students need only to learn the skills and are not interested in the theoretical side. On the other hand, he stressed that in some courses offered to students specializing in mathematics, for example topology or set theory, in which the focus is on the production and study of proofs, software use is useless.

There is not enough time to prepare other approaches or deviate from the syllabus

Some interviewees (e.g. A4, B1) expressed that with the heavy and fixed content mathematical curriculum and given the limited number of lectures that were allocated to cover all that, there was little time if a lecturer wanted to go in the details of Matlab, Mathematica, etc. This was because the lecturer would then have to devote at least two lectures, or perhaps more, just to cover the basics of the software. Also, B3 stressed that all courses in mathematics departments, especially the undergraduate courses, were coordinated, with probably more than one section having common examinations, which made deviating from the fixed syllabus even more difficult. A2 complained that in his department, most of the time they were not told which course they were going to be teaching before the commencement date of a semester. He added that if he did not know what course he would teach, he could not prepare well-thought-out notes utilizing the available software; such preparation would certainly need more time.

Software use is not assessed

Interviewees from both departments (e.g. A5, B6) stated that the use of software was not assessed. Software was not allowed during examinations in most of the courses offered by the mathematics departments in the two universities. A1 stated that in some of the introductory courses (e.g. calculus courses) students were only allowed to use basic (non-programmable) calculators during examinations.

A5, who was teaching a numerical analysis course, stated that students were not interested in learning about software because they were only required to work on one homework assignment in which the use of software was required. He felt that many students and lecturers would not be interested in using software unless they were 'forced' to do so by including software use in in-class examinations in any form. B5 argued that the use of software could not be assessed in class even in computational mathematics courses, because in his view, it was illogical and impractical to ask the students to write a programme during an in-class examination. He felt that it would be very difficult for the student to write a good programme, debug it and expect good results to come out in the time allocated for an in-class exam. He added that the student may fail an exam simply because he or she could not debug the programme on time.

The prevailing culture in mathematics departments is not to use software

In both mathematical departments, there was a general encouragement to use ICT, but a more laissez-faire approach to implementation. In relation the use of software in line with the objectives of the curriculum, direction and support were limited. Lecturers from both departments reported that the prevailing method of teaching was the traditional board-based approach. Some lecturers reported that in their department there was more emphasis on research rather than teaching, since promotions of faculty members depended on the research they produced and did not depend on the quality of teaching they provided, or as B2 put it: 'so would a faculty spends some time thinking how do I improve my teaching style. Well, I will go give my lecture_ who cares? as long as I am doing my research. Why I would care about really working hard to develop whatever thing to prepare my lectures and integrate technology'. B3 reported giving a seminar for the faculty members in his department on how to integrate software into mathematics teaching. He asserted that the attendees were very happy about that seminar and they actually called for another short course. However, he added that there was a difference between being enthusiastic about the use of software in teaching and actually applying it in their lectures, and he emphasized that such changes may need some time, even for those who were very excited about them.

It is difficult for an individual lecturer to design course materials that involve the use of software—there needs to be collaboration

There were calls for more cooperation between lecturers to produce modern curricula that included the use of software. A4 complained that collaboration was somehow missing in the mathematics department where he taught. He stated that everyone was sitting in his office and they were not working as a community. A1 drew a distinction between two different things when it comes to using mathematical software. He stressed that the first case that he may not be that enthusiastic about was designing course materials, or trying to build interactive lessons using these packages because this would require him to have advanced knowledge of how to produce this material, and it might require things that do not interest him or knowledge that is not purely mathematical. On the other hand, the issue that he was interested in knowing how to solve mathematical problems using various mathematical software packages. For this reason, B3 stressed the need for collaborative work that includes mathematicians who have used the technology and those who have not used the technology for the production of such materials. Also, A4 proposed the idea of creating a common 'cyber-class' for every mathematical course in all universities in the country. He asserted that this was the beauty of e-learning and stressed that it should be a collaborative effort where an individual lecturer was not doing it alone, but he or she was doing it with colleagues. In these cyber-classes, all students in all branches of universities in the country who enrol in this course every week will be studying the same materials, doing the same activities, doing the same assignments and sitting the same examinations. He stressed that this would have better quality management than the current situation where each individual lecturer has to create his or her own cyber-class, because teamwork and collaboration are more productive than individual work.

Summary of Chapter 4

In this chapter I present the findings from the interviews with 18 lecturers from various branches of mathematics on the use of mathematical software, and the rationale for the use or non-use of software in the teaching of mathematics and statistics courses at universities. In terms of infrastructure and the ICT environments, all the participants indicated that they were satisfied with the ICT facilities at their universities. With regard to the LMS, Bb systems were used at both universities. The first year for the use of LMS was 2011 at one university, while the other had used LMS for years. At both departments of mathematics, all classrooms and lecture halls were equipped with a computer, a projector, an IWB and an electronic lectern.

In terms of the use of mathematics software, lecturers' use was differentiated. Software was highly used in computational mathematics and statistical courses, and less so in calculus and the other courses in which such use was not required.

The factors that encouraged the use of software were either beliefs about value of software or contextual. The former included: software offering automated features that enable lecturers to calculate things very quickly or produce displays that would be impossible otherwise; it assisted visualization; and it made things clearer by refocus attention from calculations to big ideas. The latter included: easy access to ICT, and the use of software was applicable or even essential (e.g. in statistics) in some courses.

Barriers to the use of software were either doubts about the value of software or contextual barriers. Doubts about the value of software included: a belief that when it came to teaching mathematics, it was more natural to use ‘chalk and board’; a concern that student could become over reliant on the software; a belief that students needed to make the effort and spend more time learning mathematics from first principles before resorting to ready-made functions. Contextual barriers included: software was seen as particularly inappropriate for some courses; there was little time to deviate from heavy and fixed content curriculum; software was not assessed; the prevailing culture in mathematics departments was not to use software; and it was difficult for an individual lecturer to design course materials that involve the use of software.

Chapter 5 Survey Analysis

5.1 Introduction

In this chapter, I will analyse the responses to the questionnaire that was administered to 421 lecturers in the departments of mathematics and statistics at 8 universities in Saudi Arabia. The findings are organised in three sections. First, I will describe respondents and their attitudes towards, and experience of, using software. Second, I shall break down these findings by variables, subject specialism and use of software in teaching in particular. Third, I will conduct an inferential analysis of the association between the key variables and the use of software in teaching.

Respondents

Table 20: Means of delivering the questionnaire

	N (recipients)	N (respondents)
printed version	170	109
online version	251	42
Total	421	151

As shown in Table 20, 151 lecturers completed the questionnaire (109 completed paper copies, while 42 completed the electronic version). The response rate was estimated at 36%. The questionnaire data were input and analysed using SPSS software.

5.2 Overall findings

This section provides the overall findings in respect to demographics, the use of software and the factors influencing the use of software in teaching.

5.2.1 Demographics

Teaching experience

Table 21: Years of teaching experience in higher education

	N	%
less than six years	11	7
6–10 years	28	19
11–15 years	46	31
16–20 years	26	17
more than 20 years	40	27

N = number of respondents; % = percentage of respondents

As shown in Table 21 above, about a quarter of the respondents were fairly new (with less than 10 years of experience) to teaching university-level mathematics. Most were either mid-career or later in their career (more than 11 years of experience teaching university mathematics and statistics).

Gender

Table 22: Gender of the respondents

	N	%
Male	130	86
Female	19	13
Undisclosed	2	1

In terms of gender, the vast majority (86%) of the respondents were male (Table 22). There were two reasons for this: first, for cultural reasons, I only had face-to-face contact with male lecturers, and second, most lecturers in the overall population were male; note that some courses in the female sections were taught by males via closed-circuit television. An estimate based on e-mail addresses available through the university websites suggests that there were around 80 females in the population, suggesting that females were under-represented, but not unrepresented, in the sample.

Subject specialism within mathematics

Table 23: Respondents' subject specialisms

	N	%
pure mathematics	49	32
applied mathematics	36	24
computational mathematics	33	22
statistics	33	22

The respondents were classified according to their major research interest (Table 23), and there was a fairly even spread across interests. Just under a third identified their interest as pure mathematics (such as algebra, analysis, topology and number theory), around a quarter as applied mathematics (using mathematical techniques to solve real-world problems, and topics such as financial mathematics, dynamical systems, fluid mechanics and mathematical biology), and 22% identified their interest as computational mathematics (running numeric computations to solve problems). The remaining 22% specialised in statistics and operation research. This clearly demonstrates the breadth of modern mathematics and is representative of the teaching that goes on in the faculties.

Students taught

Table 24: The respondents' students

	N
mathematics students	115
statistics students	44
introductory courses	83

In terms of the students who were attending their courses, the findings show that the respondents were teaching mathematics students, students majoring in statistics and students with other majors who were taking introductory mathematics courses (Table 24).

Courses taught

Table 25: Courses taught

	N
Calculus	72
Differential equations	41
Statistics	37
Linear algebra	34
Numerical analysis	30
Partial differential equations (PDE)	29
Abstract algebra	25
Multivariable calculus	22
Analysis	20
Operation research	12
Topology	9
Geometry	5

Table 25 shows the considerable, but expected, range of courses taught, with calculus being by far the most frequently mentioned course (72 respondents). The second-most frequently mentioned course was differential equations (41 respondents), followed by linear algebra (34 respondents). Numerical analysis was reported by 30 respondents. Statistics (37 respondents) and operation research (12 respondents) were, as expected, mentioned by those whose identified research focus was statistics. A follow-up analysis indicated that 89 lecturers were teaching more than one course. This mix of teaching is probably typical of mathematics departments in most countries. Further, an example analysis showed that many respondents were teaching a mix of single and multivariable calculus, linear or abstract algebra and differential equations with one or more of the upper-level courses, such as partial differential equations (PDE) or numerical analysis.

5.2.2 Use of software

Use of software in research

Table 26 shows that only 6 respondents (4%) reported that they had never used software in their research. This clearly indicates that almost all of the respondents (96%) were not only familiar with software but were also, to varying degrees, software users. This was not a surprising finding. A follow-up analysis revealed that all six non-users came from non-computational subjects (four were pure mathematicians and two were applied mathematicians).

Table 26: Use of software in research

	N	%
Never	6	4
Rarely	29	19
Sometimes	34	23
Often	21	14
Always	61	40

Use of software as a student

Table 27: Use of software as a student

	N	%
yes	122	81
no	29	19

It is sometimes suggested that teachers are influenced by their own personal use of software when making decisions about using ICT. Table 27 shows that only a minority of respondents (19%) had not used software when they were students. Analysis revealed that these tended to be respondents who were later in their career (more than 15 years of teaching experience) and pure mathematicians.

Use of software in teaching

Table 28: Software use in teaching

	N	%
never	40	27
25% or less	25	17
26–49%	32	22
50–74%	26	17
75% or more	26	17

One of the key questions of this research was about the respondents' use of mathematical software in teaching. As shown in Table 28, most of the respondents (73%) reported, albeit to varying degrees, some use of software. This question enabled the identification of lower and higher software usages. Throughout the later analysis of the survey, the 44% of the respondents who either did not use any software in their teaching or who used software in no more than a quarter of their lectures during the semester will be grouped and labelled as 'no/low users' (n = 65), while the 34% respondents who used software in more than half of their lectures (n = 52) will be grouped and labelled as 'high users' (see Table 29). The middle group (26–49%) was not included in the breakdown of the data in section 2 of the chapter.

Table 29: Software use in teaching

	N	%
no/low users	65	44
high users	52	34

Where software was used

Table 30: Where software was used

	N
I use software in a lecture room	101
I assign homework which requires the use of software	79
I use software in a computer lab	64

Table 30 shows that software was used in different settings. The most frequently cited setting was the lecture room, which was shown, via interviews, to generally cover the projection of presentations and demonstrations of software. Just over half of the respondents reported assigning homework that required the use of software, and just under half mentioned that they had used software packages in a computer lab.

Purposes of using software in teaching

Table 31: Purposes of software use in teaching

	N
symbolic manipulation	92
visualization	82
numerical computations	64
as a programing language	59
statistical analysis	52

The respondents were given five options to explain the rationale, as generated from the interviews and the literature, for using software in teaching. These were not exclusive categories, as many respondents chose more than one answer. As seen in Table 31, the most frequently cited rationale for using software concerned symbolic manipulation, such as integrating a function or solving a system of linear equations (92 respondents out of 138 reported such use). The second-most frequently cited rationale, reported by

82 respondents, was to help students visualise mathematical objects (graphs or geometric shapes). Out of 139 respondents, 64 reported using software for numerical computation, as is usually the case in numerical analysis courses, whereas 59 (out of 139) stated that they used packages in their lectures as programming languages, allowing them to implement their own codes. Furthermore, all statisticians, as well as some mathematicians, in the sample reported using software packages for statistical analysis purposes (52 out of 139).

Most commonly used software packages in teaching

Table 32: Most commonly used software packages in teaching

	N
Matlab	49
Mathematica	48
Excel	36
SPSS	35
SAS	29
Maple	27
Scientific workplace	11
Lingo	9
Mathcad	8
Tora	6

Matlab (49 respondents) and Mathematica (48 respondents) were the most frequently used software packages. Both packages are known to be popular with lecturers in many universities throughout the world. Matlab is used for numeric computation, while Mathematica is used widely for symbolic calculation. In addition, Maple (27 respondents), which is a symbolic manipulator similar in many aspects to Mathematica, and SPSS (35 respondents) and SAS (29 respondents), which are both statistical packages used widely in statistics courses, were mentioned frequently. Furthermore, 36 respondents mentioned using the spreadsheet software Excel. Some respondents mentioned Tora and Lingo, which are widely used for optimization and decision-making problems in operations research courses (Table 32).

General software

More than half of the respondents (84 respondents) reported using presentation software during lectures; the interviews clarified that this was PowerPoint. This was slightly higher than I had expected, based on my own personal experience. While this might suggest a bias in the responses, a more likely explanation is that the use of PowerPoint has become much more common since I began my study. A slightly lower number (59 respondents) reported using a smart board for teaching mathematics and statistics courses (Table 33).

Table 33: Use of general software

	N
presentation software (e.g. PowerPoint)	84
Smart Board	59

Virtual learning environment (VLE)

Table 34: VLE use

I use the VLE for:	N
posting lecture notes	105
supporting materials, such as past exams	98
Quizzes	62
e-mailing students	51
setting and submitting online homework	37
discussion forums	21

With respect to the VLE, the use of Blackboard (Bb), WebCT and other course management software, was quite high, with only 35 respondents reporting not having used such tools. An explanation provided during the interviews was the direction from the universities. As seen in Table 34, the most common use of the VLE was for publishing lecture notes for students and for posting support material, such as past exams. This suggested that the communication was one way, that is, from lecturers to students; although 21 lecturers had set up forums, it is impossible to tell from the survey itself how frequently these were used, or what the lecturer's role was in the forums.

5.2.3 Factors influencing the use of software in teaching

Access

Table 35: Access to software, technical support and computer labs

	N	SD %	D %	Ne %	A %	SA %
projection systems are available in most lectures rooms	150	2	5	4	67	22
I have access to the software I need for teaching	147	3	11	20	56	10
I have access to technical support	149	2	24	28	41	5
it is not difficult to schedule a class in a computer lab	148	2	19	24	41	14
most entry-level courses are too large for the available computer labs	139	4	17	22	46	11

SD = strongly disagree; D = disagree; Ne = neither agree nor disagree; A = agree; SA = strongly agree

Table 35 shows that projection systems were available in most lecture halls, with nearly everyone agreeing or strongly agreeing with this. However, the fact that about 7% of the respondents disagreed with the statement suggests a shortage of facilities. Regarding access to software packages, 66% of the respondents agreed or strongly agreed that they had access to the software packages they needed for teaching. On the other hand, some expressed disagreement or strong disagreement, or neither agreed nor disagreed. This suggests quite good access to software, but with some clear gaps.

Table 35 also shows that most respondents felt they had adequate technical support, but about a quarter of them disagreed. This suggests that technical support could not be taken for granted.

Regarding access to computer labs, the responses in Table 35 show that 55% of the respondents reported agreement or strong agreement that they did not have difficulty scheduling a class in a computer lab. On the other hand, there was some disagreement or strong disagreement with this. When asked whether they agreed that most entry-level classes were too large for the available computer labs, 57% of the respondents agreed or strongly agreed that this was the case, while only 21% disagreed or strongly disagreed. This was another indication of the difficulties in accessing computers (and in practice computer labs) for most introductory classes.

The respondents were also asked whether they found appropriate software difficult to access, and 67% either disagreed or strongly disagreed, indicating that appropriate software was available. Again, a minority found software difficult to access, suggesting there is some room for improvement (see Table 36). There is consistency when we compare these responses with the responses to a previous item in Table 35 which inquired about the ease of access to software packages (and not about the difficulty of access, as in this item).

Table 36: Appropriate software is difficult to access

	N	SD %	D %	Ne %	A %	SA %
I find the appropriate software difficult to access in my university	141	12	55	18	13	2

Overall, the respondents had access to software, and while most felt that they had access to what they needed, problems remained, such as labs needing to be booked and some class sizes exceeding the capacity of the labs.

Training and support

Table 37: Technology training

	N	Yes %	No %
have you ever participated in any technology training provided by your department or elsewhere?	149	77	23
I would be happy to attend technology training workshops	149	91	9

A large majority of the respondents reported having participated in training workshops about using technology in teaching, whether these workshops were held in the mathematics department, in the IT services at the university or outside the university. As for their willingness to attend such workshops, 91% reported that they would attend (Table 37). This suggests a high level of interest in using software; however, these were general questions which covered training for generic software as well as mathematical software.

Two questions were posed regarding the specific use of mathematical software. The first question asked if they agreed or disagreed that there was enough training for lecturers wanting to teach using software.

The second question asked whether they agreed that there was not enough support for lecturers wanting to integrate software into their teaching. Their responses are summarized in Table 38. The respondents gave similar responses to both questions. Most reported that there was not enough support or adequate training for lecturers wishing to use software in their teaching. About 47% thought that there was not enough training, and a similar percentage (48%) thought that there was too little support for lecturers wishing to integrate software into their teaching. These responses show that despite the availability of software and overall good access to ICT resources reported earlier, most of the respondents were not satisfied with the level of support and training they received.

Table 38: Training and support

	N	SD %	D %	Ne %	A %	SA %
there is enough training for lecturers who want to teach with software	139	5	42	30	22	1
there is too little support for lecturers who want to integrate software in their teaching	139	4	23	25	42	6

Stance on technology

Overreliance on software

Table 39: Overreliance on software

	N	SD %	D %	Ne %	A %	SA %
using software distracts students from understanding concepts	149	19	27	16	19	19
students may use software to provide answers with little understanding	150	16	16	16	37	15
the focus in introductory courses should be on math rather than on learning to use software	144	16	30	17	21	16
the use of software for teaching undergraduate math does more harm than good	149	17	38	16	15	14
software packages are useful for doing math, not for learning math	140	8	41	5	35	11

Five items explored overreliance on software, which, as reported earlier, was seen as leading to the weakening of students' mathematical understanding. The respondents had very mixed views (Table 39). The first item concerned whether using software in teaching distracted students from understanding mathematical concepts. Nearly half of the respondents disagreed or strongly disagreed, suggesting a largely positive perception of the contribution of software to teaching; nevertheless, a sizeable minority of respondents felt that software was distracting. In a related item, just over half of the respondents

(52%) agreed or strongly agreed that some students might use software to provide answers with little understanding of the mathematical concepts (the second row in Table 39); slightly less than a third (32%) disagreed. Again, this indicates that there was a widely shared concern about the use of software and implied support for the proposition that students may misuse it as a 'black box' providing answers, with little understanding of what was going on inside the 'box' or the mathematical justification of whatever the software was doing.

In response to an issue that was raised by the lecturers who were interviewed in the first part of this study, Table 39 shows that 46% of the respondents disagreed or strongly disagreed that students in introductory courses should focus on mathematics rather than on learning to use software, and 37% either agreed or agreed strongly. This suggests a split opinion as to what should be the focus of teaching, especially in the early stages of university education. A similar question asked whether the respondents thought the use of software for teaching undergraduate mathematics did more harm than good. Here, just over half disagreed or strongly disagreed, while 29% either agreed or strongly agreed. This is part of a pattern of support for using software, and the concerns and anxiety expressed by a sizeable number of respondents as to the consequences of its use.

An important point, which was mentioned by a mathematics lecturer in the pilot phase of this study, was the distinction between using software when learning mathematics and using it when doing mathematics (i.e. as a tool once one understands the principles). When asked about this, there was a nearly equal balance of opinions (the fifth row in Table 39). If anything, this suggests that a large proportion of the mathematics lecturers were still not fully convinced of the positive benefits of the students using the software to learn mathematics. This uncertainty may perhaps be due to the perception that these software packages have been designed primarily for professional mathematicians, and not specifically for mathematics learners.

All the above indicates that there were still some concerns among some mathematicians as to the usefulness or danger of using software packages in learning or teaching university mathematics, and that some feared that students may rely upon the software to provide answers with little understanding. Moreover, there was diversity in the views on what should be the focus of learning, especially in the early stages of university education, and whether the use of software may help or 'hurt' students in their learning at this particular stage.

Perceived benefits of using software

Epistemic value

Table 40: Epistemic value of using software

	N	SD %	D %	Ne %	A %	SA %
software use helps to refocus teaching away from time-consuming calculations	140	1	5	6	69	19
students learn math better with software	140	2	26	14	44	14
software use enables students to become better problem solvers	141	2	28	16	43	11

There were three items in the questionnaire asking the lecturers whether they believed that the use of software had an impact on students' learning. Perhaps it is not surprising to see that the item regarding the use of software for helping to focus the teaching away from time-consuming calculations was one of the few items in this questionnaire upon which the overwhelming majority of the respondents agreed (Table 40). In the second item in Table 40, the respondents were asked whether students learn mathematics better with software. More than half (58%) indicated that they either agreed or agreed strongly with this, while 28% disagreed. The third item in Table 40 asked whether the use of software could enhance students' abilities to solve mathematical problems. The majority (54%) agreed, whereas 30% did not agree. These items show that a majority sees the use of software as supportive for students' learning. However, a sizable number remain unconvinced.

Teaching value

Table 41: Value of software for teaching

	N	SD %	D %	Ne %	A %	SA %
software allows me to represent concepts in different ways	140	0	6	14	59	21
I can explain concepts more easily using software	139	0	16	17	53	14
teaching is more interactive using software	140	0	12	12	61	15

Other items in the questionnaire inquired about the value of using software as a teaching tool. There was a great deal of agreement that software helped the teachers represent concepts in different ways (first row in Table 41). This can likely be understood as referring to representing mathematical functions using graphs, numbers and symbols. When the respondents were asked whether a mathematics lecturer could explain mathematical concepts more easily using software, about 67% agreed or strongly agreed, while only 16% disagreed (second row in Table 41). As far as increasing interactivity in teaching, about two thirds (76%) thought that using software for teaching mathematics courses increased interactivity, while only 12% thought otherwise. These items show that most of the lecturers felt positively about the use of software, believing it to be more interactive and help explanation.

Motivational value

Table 42: Motivational value

	N	SD %	D %	Ne %	A %	SA %
students like to see lecturers using software packages in their teaching	139	1	10	34	48	7
students don't like using software themselves	141	4	44	31	21	0

Table 42 shows that more than half (55%) agreed or strongly agreed that students want lecturers to use software in their teaching, while 11% disagreed, and nearly half of the respondents (48%) disagreed or strongly disagreed that their students did not like to use the software themselves. These responses suggest that most of the respondents believed that using software had a positive motivational impact on the students.

To sum up, in this part of the survey, a majority of the respondents appreciated the value of software for teaching, for example, as an aid for explaining mathematical concepts, for learning, for example, in helping students to become better problem solvers, and for motivation. Nonetheless, a sizable number of respondents remained unconvinced.

The next part of the survey explored the influence of the curriculum by investigating the respondents' perspectives on the curriculum itself, its assessment and time spent using ICT.

Curriculum

In almost all university-level courses, the curriculum is established in advance, and in practice it is difficult to adapt. According to the interviews, the lecturer did not have the freedom to change topics, or to propose a change in the textbooks, unless granted approval by special committees, using specific procedures. The items in the survey covered the issue of the extent to which the syllabus facilitated the use of software and whether it was difficult to deviate from the predetermined curriculum.

Table 43: Curriculum requirements

	N	SD %	D %	Ne %	A %	SA %
the courses that I teach do not require the use of software	140	19	29	6	41	5
the syllabus limits the use of software	139	5	30	11	50	4

The responses, shown in Table 43, show no clear majority in either direction; 46% of the respondents did not believe that there was a need to use software in their courses, and a slightly higher proportion (48%) disagreed. This suggests that some courses require the use of software more than others. Examples of such courses include all computational mathematics and statistics courses, where the use of software is built into the course design. However, it is possible that what one mathematician might see as required might not be the same for another mathematician in the same department. For example, some lecturers could believe that software is needed when teaching calculus to be able to, say, visualize three-dimensional shapes, while others might think differently. In another item, when the respondents were asked whether the syllabus in the undergraduate mathematics programme limited the use of software, just over half (54%) agreed or strongly agreed, while a little more than a third (35%) did not agree. This suggests that the curriculum was an obstacle to many of the lecturers limiting the wider use of software in teaching. However, the respondents were divided when asked whether they favoured changing the syllabus to increase the use of software. While 47% were opposed to this proposal, 41% were in favour of modifying the syllabus (Table 44). Thus, the mathematicians were not in agreement about reforming the curriculum to include more software use.

Table 44: Modifying the syllabus

	N	SD %	D %	Ne %	A %	SA %
the syllabus should be modified to increase the use of software	138	6	41	12	33	8

Assessment

The use of software during examinations has always been an issue of concern among some mathematicians as well as mathematics educators (Chapter 2). Table 45 shows that the respondents were divided when asked whether they agreed that it was difficult to assess the students' knowledge if they could use software to do tests. On this topic, 45% expressed either strong agreement or agreement, while about the same proportion disagreed. This indicates that many of the respondents were not at ease with allowing students to use software during tests, and that allowing the use of software made it difficult, or perhaps even impossible for some, to assess the students. In a related item, the respondents were asked whether they agreed or disagreed that students did not pay attention to the use of software because it was not included in tests. Table 45 shows that about one third (34%) disagreed, while about half (49%) agreed. This shows a widespread assumption that teaching and learning are assessment driven. It might also indicate that unless the assessment requirements are modified to include the use of software, many of the students and their lecturers may not consider very seriously the use of the software in the learning and teaching of mathematics.

Table 45: Assessment issues

	N	SD %	D %	Ne %	A %	SA %
it is difficult to assess what students know if they can use software to do tests	141	5	38	12	42	3
students do not pay attention to the use of software because it is not included in tests	137	4	30	17	44	5

Many respondents seemed to view assessment as an important issue, and hence it cannot be overlooked when studying the factors that affect the use of software in mathematics teaching.

Time

When asked whether there was a lack of sufficient time to include software in the curriculum, the 138 respondents were divided, as 45% disagreed or strongly disagreed, while 39% agreed (Table 46). A related item asking whether it took too long to develop software-related teaching materials yielded responses which were very consistent with the answers to the previous item: 47% either disagreed or strongly disagreed, while about 38% agreed.

Table 46: Time constraints

	N	SD %	D %	Ne %	A %	SA %
there isn't enough time to incorporate software into the curriculum	138	5	40	16	36	3
it takes too long to develop software-related teaching materials	139	7	40	15	36	2

To summarise, the curriculum and the assessment policies were obstacles for many of the respondents, but facilitators for others. A lack of time was an important issue for those teaching a full curriculum in which the use of ICT was not formally assessed.

Confidence and competence

Table 47: Confidence and competence in using software

	N	SD %	D %	Ne %	A %	SA %
I don’t feel confident using software in my lectures	141	17	31	12	36	4
I don’t know how to integrate software into my teaching	141	18	60	10	11	1

The item in the first row of Table 47 explored the respondents’ confidence in using software in their lectures, with nearly half (48%) expressing confidence, while a slightly smaller proportion (40%) did not feel confident. However, a larger number (78%) disagreed that they did not know how to incorporate software into their teaching. Even allowing for some inconsistency, this suggests that most of the respondents understood what software could offer to the teaching of mathematics.

Intention to use software

Table 48: Intention to use software in teaching

	N	SD %	D %	Ne %	A %	SA %
I would like to use software more in my teaching	141	2	30	15	42	11

When asked whether they had the intention to use software more often, more than half (53%) of the respondents agreed or strongly agreed, while about one third disagreed (Table 48). This suggests that some mathematicians (a large minority here) remain resistant to change by not even considering the thought of using software in their teaching.

Wider environment

Table 49: Departmental influences

	N	SD %	D %	Ne %	A %	SA %
my department encourages the use of software in teaching	139	3	19	34	40	4
most of the lecturers within the math department use software in their teaching	137	7	62	16	13	2
only a few of my colleagues are enthusiastic about using software in their teaching	139	3	11	17	60	9

Three items asked the respondents whether they were encouraged by their colleagues to use software in their teaching. When asked whether their departments encouraged them to use software in teaching, just under half (44%) of the respondents agreed or strongly agreed, while nearly a quarter (22%) disagreed (Table 49). The majority (69%) reported that most faculty members within their departments did not use software in their teaching. This is not entirely consistent with the earlier finding about the levels of use in teaching (see Table 28), possibly suggesting that the respondents did not know about their colleagues' use of software or that they had a stricter understanding of use; for example, perhaps they meant regular use. Whatever the cause, this result suggests that the respondents were not working in environments in which ICT was seen as a topic for discussion and promotion. To test reliability, a similar question was asked in reverse: whether only a few of their colleagues were enthusiastic about using software in their teaching. The findings were consistent with the responses to the second item in Table 49. All of this suggests general encouragement for using ICT, but also a somewhat laissez-faire approach to implementation.

How should it be?

Table 50: How should it be?

	N	SD %	D %	Ne %	A %	SA %
all math lecturers should use software at times in their teaching	140	5	42	18	28	7
it should be left up to the lecturer whether or not to use software	140	3	21	8	58	10
software should be used to supplement teaching	141	2	16	12	60	10

Three items in the questionnaire investigated the lecturers' views on the promotion of software. Specifically, the respondents were asked if all lecturers should use software at times in their teaching. Nearly half (47%) of them rejected this statement, and just over a third agreed (Table 50). With respect to a follow-up item concerning whether it should be left up to the lecturer to use software, 68% of the respondents supported this proposition, while 24% opposed it. This shows the consistency in the respondents' answers on this issue, and suggests a lack of consensus, or even a majority view, in favour of making software compulsory. Those who set the curriculum may, of course, decide to make it compulsory, but the findings suggest that they will need to support lecturers with training and hands-on support.

Perhaps one of the most important items that may determine the respondents' perspectives on the role that software packages are supposed to play in the teaching of mathematics at the university level is the item asking the respondents whether or not they thought software should be used to supplement teaching. The results in Table 50 show that the vast majority—slightly less than two thirds of the respondents (70%)—agreed or strongly agreed that software should supplement teaching. It is difficult to interpret this response. It may well mean that many lecturers were quite comfortable with traditional (so called 'chalk and talk') teaching. However, some may simply be making the point that learning mathematics is a cognitive rather than purely practical undertaking.

5.3 Breaking down the findings

The no/low user and high user groups which were identified earlier enabled a breakdown of the findings in particular in relation to subject specialisms.

5.3.1 Breakdown by specialism

As seen in the first part of the analysis, the identification with a branch of mathematics was considered a very important factor in the use of software, according to the interviews. Statisticians and computational mathematicians were more likely to be users of software because they were teaching courses that required the use of software (for example, numerical analysis, in which computational techniques are applied using software to solve a wide range of problems, and statistical inferences). Perhaps, then, as they were familiar with, and habituated to, using software, they were more likely to use it when teaching other courses, such as calculus courses. In contrast, pure mathematicians were less likely to use software, as their focus was on abstract concepts which were mostly inapplicable to software usage. Here, the various findings are broken down by identification with a branch of mathematics in order to understand how this influences software usage.

The respondents were classified into two categories: non-computational and computational groups. The former included respondents specialising in pure and applied mathematics, while the latter included respondents for whom the use of computational tools (hence, the use of software) was more common, namely, computational mathematicians and statisticians (see Table 51). An important point here is that, as some of the mathematicians who were interviewed in the first phase of the study pointed out, at the undergraduate level, applied mathematics courses focus mainly on the theoretical foundations and do not require the use of software.

Table 51: Respondents' research interest broken down by computational focus

	N	%
non-computational subjects	85	56
computational subjects	66	44

Use of software by specialism

Taking a closer look at those who never used software in lecture rooms, cross-tabulation (Table 52) shows that the non-computational specialists (43%) were much more likely than the computational specialists (7%) to never use software in lectures. A probable explanation is that the non-computational group members generally teach topics of an abstract nature, such as topology, real and complex analysis, group and Galois theories, etc., for which software is not considered essential. They may also teach applied mathematics courses at the undergraduate level, which are foundational courses, primarily comprising ordinary and partial differential equations, in which the use of software is not required.

Table 52: Never used software in the lecture room, broken down by subject specialism

	N	%
non-computational specialists	33	43
computational specialists	4	7

In contrast, 19 out of the 24 respondents who always used software in the lecture room were computational mathematicians or statisticians (Table 53).

Table 53: Always used software in the lecture room, broken down by subject specialism

	N	%
non-computational specialists	5	7
computational specialists	19	31

Among the computational specialists, 75%, compared with only 23% of the non-computational specialists, used software in a computer lab setting (Table 54). This is not at all surprising, since statistics and computational mathematics courses generally require software-based computations, and the use of the lab is timetabled.

Table 54: Used software in the computer lab, broken down by subject specialism

	N	%
non-computational specialists	18	23
computational specialists	46	75

In addition to utilising software in a lecture room or computer lab, Table 55 shows that the non-computational specialists were less likely, compared with the computational specialists, to assign homework involving the use of software. Again, these are expected findings.

Table 55: Assigned homework requiring the use of software, broken down by subject specialism

	N	%
non-computational specialists	23	30
computational specialists	56	92

Stance on software by specialism

As regards the respondents' stance on software, the computational group was more positive. While 52% of the non-computational specialists agreed or strongly agreed, only 21% of the computational specialists agreed or strongly agreed that software was distracting (Table 56). This shows how one's identification with a branch of mathematics tailors one's view of software. Table 56 further shows that the respondents specialising in non-computational mathematics were more likely to believe that the use of software could do more harm than good. What is perhaps more striking is that nearly a quarter of the computational specialists, who rely heavily on software, also held this view.

Table 56: Agree or strongly agree with statements about distraction

	Non-computational specialists (%)	Computational specialists (%)
the use of software distracts students	52	21
software does more harm than good	35	23

The respondents with non-computational specialisms were more likely than their colleagues with computational specialisms to doubt the value of software in improving students' abilities to solve problems, to explain concepts more easily or to enhance the students' learning (Table 57).

Table 57: Disagree or strongly disagree with statements about the value of software

	Non-computational specialists (%)	Computational specialists (%)
software use enables students to become better problem solvers	36	20
I can explain concepts more easily using software	46	15
students learn math better with software	42	11

Table 58 shows that 20% of the non-computational specialists thought that teaching with software was not necessarily more interactive, while only 2% (1 respondent) of the computational specialists thought the same way. Moreover, 15% of the non-computational specialists felt that students did not want to see lecturers use software, compared with only 5% of the computational specialists.

Table 58: Disagree or strongly disagree with statements about value of software

	Non-computational specialists (%)	Computational specialists (%)
teaching is more interactive when using software	20	2
students like to see lecturers use software packages in their teaching	15	5

To sum up, these findings indicate that the computational specialists were less concerned with the overreliance on software and had a more positive outlook about the value of software in learning and teaching.

Curriculum, assessment and time by specialism

In the first part of the analysis, it was established that the curriculum and the assessment policies were obstacles for most respondents. With regard to how the computational and non-computational groups perceived these issues, it is perhaps not surprising that the non-computational specialists (71%) were more likely than the computational specialists (33%) to think that the syllabus in the undergraduate mathematics programme limited the use of software (Table 59).

Table 59: Agree or strongly agree that the syllabus limits the use of software

	Non-computational specialists (%)	Computational specialists (%)
the undergraduate mathematics syllabus limits the use of software	71	33

The non-computational specialists were more likely to feel that software would make assessment difficult (Table 60).

Table 60: Agree or strongly agree that assessment will be difficult if software is allowed for doing tests

	Non-computational specialists (%)	Computational specialists (%)
it is difficult to assess what students know if they use software to do tests	68	15

Table 61 shows that the non-computational specialists were more likely to feel that there was not enough time to incorporate software into the mathematics curriculum.

Table 61: Agree or strongly agree that there is not enough time to incorporate software

	Non-computational specialists (%)	Computational specialists (%)
there is not enough time to incorporate software into the mathematics curriculum	55	17

Again, to sum up, the respondents with non-computational specialisms considered the curriculum, assessment and time as obstacles in a way that the respondents with computational specialisms did not.

Competence by specialism

As Table 62 shows, one fifth of the non-computational specialists agreed or strongly agreed that they did not have the knowledge of how to integrate software into their teaching, whereas none of the computational specialists felt that they lacked such knowledge. This is likely because software was already integrated into the computational mathematics and statistics courses, and not into the other non-computational courses.

Table 62: Agree or strongly agree with the following statement about competence

	Non-computational specialists (%)	Computational specialists (%)
I don't know how to integrate software into my teaching	20	0

Intention to use software by specialism

As Table 63 shows, 41% of the non-computational specialists, compared with only 20% of the computational specialists, reported that they had no intention to use software more often. This suggests that the non-computational specialists were resistant to change in relation to their use or non-use of software. These results suggest that it is likely that the pattern of use will remain unchanged between the computational and non-computational specialists.

Table 63: Disagree or strongly disagree with the following statement about intention

	Non-computational specialists (%)	Computational specialists (%)
I would like to use software more often in my teaching	41	20

Wider environment by specialism

As in Table 64, the computational specialists (66%) were more likely than the non-computational specialists (28%) to think that their departments encouraged the use of software in teaching.

Table 64: Agree or strongly agree the following statement about wider environment

	Non-computational specialists (%)	Computational specialists (%)
my department encourages the use of software in teaching	28	66

Table 65 shows that the respondents with computational specialisms were more likely to oppose the view that it should be left up to the lecturer whether or not to use software. This, in turn, suggests that the computational specialists were more supportive of making the use of the software compulsory in teaching.

Table 65: Disagree or strongly disagree with the following statement about the promotion of software

	Non-computational specialists (%)	Computational specialists (%)
it should be left to the lecturer whether or not to use software	13	38

To summarise, compared with the non-computational specialists, the computational specialists were much more likely to always use software in lectures, to use software in a computer lab and to assign homework involving the use of software. They also had more positive views about the benefits of using software when learning and teaching mathematics. Furthermore, they felt more competent in integrating software into their teaching, and they were less concerned about the curriculum, assessment and time constraints than the non-computational specialists. All of the above findings suggest clearly that identifying the respondents with the major branches of mathematics to which they belong was a very important classifier regarding the use of software in teaching.

5.3.2 Breakdown by level of software use in teaching

Having shown the importance of subject specialism, I went on explore the data through other factors which had been identified earlier as influencing the use of ICT. These were access, training and support, curriculum, assessment, time, confidence and competence, the wider environment and the lecturer's stance on software.

Access by level of use

The first part of the analysis indicated that access was an issue for some respondents. One would expect the no/low users to have greater access problems and experience a lack of support. Table 66 shows that 30% of the high users, compared with only 18% of the no/low users of software in teaching, expressed difficulty in obtaining technical support. This may indicate that despite its importance, technical support was not a decisive factor that in itself prevented those wishing to use software from doing so. In fact, the absence of technical support may have been felt more keenly by those wanting to use software. Table 66 also shows that 28% of the no/low users disagreed or strongly disagreed that it was not difficult to schedule a class in a computer lab. This indicates that difficulty of access was, to some extent, an obstacle to the use of software in teaching.

Table 66: Disagree or strongly disagree with the following two statements

	No/Low users (%)	High users (%)
I have access to technical support	18	30
it is not difficult to teach in the lab	28	15

Training by level of use

In regard to training, 12% of the no/low users, compared to only 4% of the high users, did not want to attend technology training sessions, suggesting that the reluctance to use ICT was higher among the no/low users (Table 67). However, many no/low users of software did want training.

Table 67: Happy to attend technology training

	No/Low users (%)	High users (%)
Yes	88	96
No	12	4

Stance on software by level of use

As shown in Table 68, the belief that software may be used to provide answers with little understanding was held more strongly among the no/low users of software than the high users. However, the fact that one third of the high users agreed with this proposition indicates the widely shared concern among the mathematicians, regardless of their level of use, that software may be misused by providing answers with little understanding of the mathematical concepts. Table 68 also shows that 54% of the no/low users agreed with the view that the focus should be on mathematics rather than on software. However, it is perhaps somewhat surprising to see that one fifth of the high users of software agreed with this view. This may suggest that some mathematicians may use the software in their teaching because they have to use it and not because of their strong conviction about its value. Further, 38% of the no/low users believed that software did more harm than good, compared with 17% of the high users. This suggests that beliefs are somewhat influential in one's disposition to use ICT.

Table 68: Agree or strongly agree with statements about overreliance on software

	No/Low users (%)	High users (%)
software provides answers with little understanding	68	33
students in introductory courses should focus on math rather than on learning to use software	54	20
software does more harm than good	38	17

The findings in Table 68 show that the no/low users were more concerned, compared to the high users, about the wisdom of using software for learning mathematics.

Not surprisingly, Table 69 shows that the no/low users of software in teaching were more likely than the high users to disagree that the use of software enabled students to become better at solving mathematical problems, that one can explain concepts more easily using software and that students learn mathematics better with software.

Table 69: Disagree or strongly disagree with statements about the value of software

	No/Low users (%)	High users (%)
software use enables students to become better problem solvers	41	10
I can explain concepts more easily using software	29	4
students learn mathematics better with software	45	10

Table 70 shows an unsurprising pattern too. Here, 88% of the high users of software in teaching, compared with only 26% of the no/low users, felt that software made teaching more interactive.

Likewise, almost all (98%) of the high users agreed or strongly agreed that students liked to see lecturers use software in their teaching, while slightly more than half (53%) of the no/low users did.

Table 70: Agree or strongly agree with statements about the value of software

	No/Low users (%)	High users (%)
teaching is more interactive using software	26	88
students like to see lecturers use software packages in their teaching	53	98

As seen, the findings show that the high users had more positive views, compared with the no/low users, about the value of using software for learning and teaching mathematics. These findings were not surprising, because the high users of software were more engaged with the software during their teaching and therefore were speaking from experience about the use of the software and how it would influence the activities inside the lecture room, and how their students perceived their use of the software in their teaching.

Curriculum by level of use

Table 71 shows that the no/low users were more likely than the high users to think that the undergraduate mathematics syllabus limited the use of software.

Table 71: Agree or strongly agree that the syllabus limits the use of software

	No/Low users (%)	High users (%)
the undergraduate mathematics syllabus limits the use of software	69	27

Further, the no/low users of software were more likely than the high users to feel that students did not pay attention to the use of software because it was not assessed (Table 72).

Table 72: Agree or strongly agree with the following statement about assessment

	No/Low users (%)	High users (%)
students do not pay attention to the use of software because it is not included in tests	69	25

Moreover, as shown in Table 73, 55% of the no/low users of software, compared to 21% of the high users, felt that there was not enough time for incorporating software into the mathematics curriculum.

Table 73: Agree or strongly agree that there is not enough time to incorporate software

	No/Low users (%)	High users (%)
there is not enough time to incorporate software	55	21

Hence, the no/low users perceived the curriculum, assessment and time as constraints on software use, whereas the high users did not.

Competence by level of use

Regarding competence, compared with only 2% of the high user, nearly one quarter of the no/low users reported a lack of knowledge about integrating software into their teaching (Table 74). Again, this is as expected.

Table 74: Agree or strongly agree with the following statement about competence

	No/Low users (%)	High users (%)
I don’t know how to integrate software into my teaching	24	2

Intention to use by level of use

Slightly fewer than half (49%) of the no/low users of software, compared with only 12% of the high users, reported that they would not like to increase the use of software in their teaching (Table 75). This suggests that the no/low users were more resistant to change in relation to their use or non-use of software.

Table 75: Disagree or strongly disagree with the following statement about intention to use software

	No/Low users (%)	High users (%)
I would like to use software more often in my teaching	49	12

Wider environment by level of use

In regard to the wider environment, Table 76 shows that the no/low users were less likely than the high users to think that their department encouraged the use of software in teaching or that the majority of the lecturers within their department used software in their teaching.

Table 76: Agree or strongly agree with the following statement about the wider environment

	No/Low users (%)	High users (%)
my department encourages the use of software in teaching	23	76
most of the lecturers within the mathematics department are users of software	3	32

Table 77 shows that the high users were more likely to oppose the view that it should be left up to the lecturer whether or not to use software. This, in turn, means that the high users were more in favour, compared to the no/low users, of making the use of software compulsory in teaching.

Table 77: Disagree or strongly disagree with the following statement about the promotion of software

	No/Low users (%)	High users (%)
it should be left to the lecturer whether or not to use software	7	39

To sum up, the high users had a more positive outlook, compared to the no/low users, on the use of software in teaching. They were less hesitant about the value of using software in the teaching and learning of mathematics. They had more knowledge on how to integrate the software into their teaching and they did not perceive the curriculum, assessment and time as obstacles to the same extent as did the no/low users. This suggests a series of interlocking factors encouraging or discouraging the use of ICT which, as argued, centred on subject specialism.

Exploring the gender factor

With regard to gender (taking into account the limited participation of female lecturers in this study), the first item in Table 78 shows that 26% of the female respondents either agreed or strongly agreed that the use of software did more harm than good, whereas 29% of the male respondents held this view. The second item in Table 78 shows that 47% of the female respondents, compared with 54% of the male respondents, either agreed or strongly agreed that students may use software to arrive at an answer with little understanding of the mathematical concepts. These responses indicate that the gender difference did not seem influential. However, the third and fourth items show a different picture. Here, 40% of the male respondents felt that students in introductory courses should focus on mathematics rather than on learning how to use software, whereas only 22% of the female respondents held this view. Likewise, while 40% of the male respondents agreed or agreed strongly with the perception that using software distracts students from understanding mathematical concepts, only 21%

of the female respondents agreed. These two latter responses suggest that the female respondents were more positive towards using software, compared with their male colleagues. However, the very limited number of females in the survey and the inability to interview female lecturers preclude a deeper understanding of gender differences.

Table 78: Agree or strongly agree with the following four statements about overreliance on software

	Males (%)	Females (%)
software does more harm than good	29	26
software provides answers with little understanding	54	47
students in introductory courses should focus on math rather than on learning to use software	40	22
using software distracts students from understanding mathematical concepts	41	21

Cross-tabulation also shows that one of the few items which showed a marked difference between the responses of the male and female respondents was the item on whether students learn better with the use of software. Here, 33% of the male respondents disagreed or strongly disagreed, while a single female respondent disagreed (6%), suggesting a less negative outlook towards the use of the software among the female respondents (Table 79).

Table 79: Disagree or strongly disagree with the following statement about epistemic value of software

	Male (%)	Female (%)
students learn math better with software	33	6

Other gender influences were explored, and the only marked differences have been reported above. I also looked at other variables, such as teaching experience, and found no remarkable findings.

This section indicates that there were still some concerns among the mathematicians, regardless of their background, gender or level of software use in teaching, as to the usefulness of using software packages while learning and teaching university mathematics. Moreover, high users and computational specialists had a more positive outlook, compared to no/low users and non-computational specialists, on the use of software in teaching.

5.4 Lecturers' beliefs about mathematics and its learning and teaching

The last part of the questionnaire aimed to explore the beliefs of the respondents regarding mathematics and how it is best learnt and taught. It comprised 10 statements—designed by Stipek *et al.* (2001)—aimed at assessing the lecturers' beliefs regarding (1) the nature of mathematics (i.e. procedures for solving problems versus a tool for thought), (2) mathematics learning (i.e. focusing on getting correct solutions versus focusing on understanding), (3) who should control students' mathematical activity and (4) the nature of mathematical ability (i.e. fixed versus changeable abilities). One more item was added to the four above regarding the lecturer's main role in lectures: whether it is to teach directly or to facilitate the students' learning. Four of these statements reflect a more constructivist approach of teaching, and four reflect a more instructional or traditional model of teaching. Table 80 displays statements of the two contrasting beliefs (Stipek *et al.* 2001; see also Ernest 1989; Beswick 2005 in Chapter 2). With regard to the item about mathematical ability, being fixed or changeable, although Stipek et al. (2001) found that more instructional beliefs were associated with the view that mathematical ability is relatively fixed, I decided to exclude the item about mathematical abilities from the analysis as such an association with pedagogy has not been well established.

Table 80: Instrumental versus constructivist beliefs (Stipek et al. 2001)

	More instrumental beliefs	More constructivist beliefs
Math as a set of operations versus a tool for thought	Mathematics involves mostly facts and procedures that must be learned	In mathematics, you can be creative and discover things on your own
Correct answers versus understanding as the primary goal	Students who aren't getting the right answers need to practice with more problems	It doesn't matter whether students get the right answer, as long as they understand the math concepts inherent in a problem
Teacher control versus some learner autonomy in classroom lessons	It's important for students to complete assignments exactly as the teacher planned	Students should construct many of their own math problems
Direct teaching versus facilitated learning	Teachers should teach directly, rather than just facilitate	Teachers should facilitate learning, rather than teach directly

It should be noted here that many of the respondents, perhaps due to the wording of this item, chose both options on the questionnaire, contrary to what was intended, which was to force a choice between the two statements. In order to distinguish the instructionist from the constructivist lecturers, all responses in which the respondents choose *both* statements were excluded. This left only 59 respondents. At this point, every statement that represented the instructionist view was given a score of 1, whereas every statement representing the constructivist view was given a score of 2. If the sum of a respondent's responses was 4 or 5, then he or she would be labelled as 'instructionist', whereas every respondent with responses that summed up to 7 or 8 was labelled as 'constructivist'. Those with a score of 6 were excluded (n = 12).

The constructivist group

Table 81 shows that the constructivist group (CG) consisted of two non-computational and five computational specialists; two of them were no/low users and five were high users of software in their lectures. There were six males and one female, and they had a range of teaching experience. This may suggest that the computational specialists and high users of software were more likely to hold constructivist views. The data did not provide an explanation or reason for such variations in pedagogical beliefs, but it is known that, unlike in pure mathematics, where the emphasis is on proofs and abstract thinking, the focus in the field of computational mathematics is on solving problems. Therefore, one can speculate that computational mathematicians possess more constructivist views because they are more focused on problem-solving activities and more open to the students' participation and involvement in their studies.

Table 81: Constructivists broken down by specialism, level of use, gender and teaching experience

Variable	Breakdown
Subject specialism	2 non-computational specialists and 5 computational specialists
Level of use	2 no/low users and 5 high users
Gender	6 men and 1 woman
Teaching experience	3 early career and 3 later career (1 mid-career)

In terms of their stance on software, five of the CG disagreed that the use of software in teaching undergraduate math did more harm than good, all knew how to integrate software into their teaching, and all but one felt confident in using software in their teaching (Table 82).

Table 82: Disagree or strongly disagree with the following three statements

	N
the use of software in teaching undergraduate math does more harm than good	5
I don't know how to integrate software into my teaching	7
I don't feel confident using software in my lectures	6

Moreover, all but one agreed that using software made teaching more interactive, five felt that their students liked to see lecturers using software to teach, and six were in favour of modifying the syllabus to include more use of software (Table 83).

Table 83: Agree or strongly agree with the following three statements

	N
teaching is more interactive using software	6
students like to see lecturers use software in their teaching	5
the syllabus should be modified to include more software use	6

Thus, one can speculate that the respondents who held constructivist views were mostly computational specialists. They were mostly high users of software in their teaching, and they showed a more positive outlook on the use of software for learning and teaching mathematics. They did not believe that the use of software in teaching undergraduate mathematics did more harm than good. However, all this is tentative, given the small number of respondents.

The instructionist group

As regards the instructionist group (IG), 17 respondents were non-computational and 13 were computational specialists. Further, 22 were no/low users and 9 were high users of software in their teaching. The IG comprised 35 men and 5 women with a range of teaching experience (Table 84).

Table 84: Instructionists broken down by specialism, level of use, gender and teaching experience

Variable	Breakdown
Subject specialisms	27 non-computational specialists and 13 computational specialists
Level of use	22 no/low users and 9 high users
Gender	35 men and 5 women
Teaching experience	9 early career and 17 later career

In terms of their stance on software, 18 (45%) of the IG felt that the use of software in teaching distracted students from understanding the mathematical concepts, 27 (68%) felt that students may use software to provide answers with little understanding of the mathematical concepts, and only 10 (25%) agreed that they would like to use software more frequently in their teaching (Table 85).

Table 85: Agree or strongly agree with the following three statements

	N
I think using software to teach distracts students from understanding the mathematical concepts	18
students may use software to provide answers with little understanding of the mathematical concepts	27
I would like to use software more often in my teaching	10

Seventeen (43%) IG members did not believe that students learn mathematics better with software, 28 (70%) did not think all mathematics lecturers should use software at times in their teaching, and 24 (60%) were not in favour of modifying the syllabus to include more software usage (Table 86).

Table 86: Disagree or strongly disagree with the following three statements

	N
students learn mathematics better with software	17
all mathematics lecturers should use software at times in their teaching	28
the syllabus should be modified to include more software use	24

As seen, the respondents who held a more instructionist view were mostly non-computational specialists. They were mostly no/users of software in their teaching and, compared to the CG, they showed less overall positive views of software usage, and they expressed greater doubt about the usefulness of software for learning and teaching mathematics. Again, the findings should be treated cautiously, given the small number of respondents.

Next, using Chi-square test of association, I will test whether the patterns and relationships that have been observed throughout this chapter are statistically significant.

5.5 Association between software use in teaching and different factors

This third section tests the associations between the respondents' level of software use in their teaching and a range of factors identified in the literature review and throughout the thesis. These factors are as follows:

1. Demographic variables, including teaching experience, gender and subject specialism
2. Access, training and support

3. Curriculum, assessment and time
4. Competence and confidence
5. Wider environment
6. Stance on software, including overreliance on software, epistemic value, teaching value and motivational value
7. Pedagogical beliefs

In exploring the data, the dependent variable was identified as the use of software in teaching, and two groups of users were considered: high users and no/low users (Table 29). The independent variables were identified as the factors listed above. In most cases, these are composite variables formed by aggregating two or more items of data. These enabled the construction of two groups within each variable. In the case of gender, this was straightforward (male and female); in the case of, for example, access, the top and bottom quartiles were chosen. This is shown in Table 87.

Table 87: How categorical variables were constructed

Variables	**Two categories**	**How categorical variables were constructed**
Subject specialism	Computational specialists and non-computational specialists	• Non-computational specialists (pure and applied mathematics; n = 85) • Computational specialists (computational mathematics and statistics; n = 66)
Gender	Male and female	• Male (n = 130) • Female (n = 19)
Teaching experience	Early career and later career	• Early career (10 years or less; n = 39) • Later career(over 15 years; n = 66)
Pedagogical beliefs	Instructionist and constructivist	• All respondents who chose both statements were excluded, leaving n = 59 • Each of the 4 statements (as shown in Table 80) that represented the instructionist view was given

		a score of 1 and each representing the constructivist view was given a score of 2 • Respondents with a total sum of 4 or 5 were labelled as 'instructionist' (n = 40), and those with a total of 7 or 8 were labelled as 'constructivist' (n = 7). Those with a score of 6 were excluded (n = 12)
Access	Concerned and unconcerned	• Five items, as shown in Table 35, were selected • The scores for agree/disagree were added to give a possible range from 5 (all strongly disagree) to 25 (all strongly agree) • The scores were ranked in ascending order • Lower and upper quartiles were identified
Training	Less satisfied and satisfied	• One item on training was used (the first row in Table 38) • 'Strongly disagree' and 'disagree' responses (n=56) formed the less satisfied group • 'Agree' and 'strongly agree' responses(n=31) formed the satisfied group
Support	Less satisfied and satisfied	• One item on support was used (the second row in Table 38) • 'Strongly agree' and 'agree' responses (n=66) formed the less satisfied group • 'Disagree' and 'strongly disagree' responses (n=37) formed the satisfied group
Confidence	less confident and confident	• 1 item on confidence was used (the first row in Table 47) • 'agree' and 'strongly agree' responses (n=57) formed the

		less confident group • 'disagree' and 'strongly disagree' response (n=66) formed the confident group
Competence	Less competent and competent	• 1 item on competence was used (the second row in Table 47) • 'agree' and 'strongly agree' responses (n=16) formed the less competent group • 'disagree' and 'strongly disagree' responses (n=109) formed the competent group
Curriculum	Hindrance and less of a hindrance	• Two items were used as per Table 43 • The scores were added to give a possible range from 2 to 10 • The scores were ranked in ascending order The lower and upper quartiles were identified
Assessment	Hindrance and less of a hindrance	• Two items (see Table 45) • The scores were added to give a possible range from 2 to 10 • The scores were ranked in ascending order • Lower and upper quartiles were identified
Time	Hindrance and less of a hindrance	• Two items (see Table 46) • The scores were added to give a possible range from 2 to 10. • The scores were ranked in ascending order • Lower and upper quartiles were identified
Overreliance on software	Hindrance and less of a hindrance	• Four items (upper four rows in Table39) • The scores were added to give a possible range from 4 to 20 • The scores were ranked in ascending order • Lower and upper quartiles

		were identified
Epistemic value	Less and more	• Three items (see Table 40) • The scores were added to give a possible range from 3 to 15 • The scores were ranked in ascending order • Lower and upper quartiles were identified
Teaching value	Less and more	• Three items (see Table 41) • The scores were added to give a possible range from 3 to 15 • The scores were ranked in ascending order • Lower and upper quartiles were identified
Motivational value	Less and more	• Two items (see Table 42) • The scores were added to give a possible range from 2 to 10 • The scores were ranked in ascending order • Lower and upper quartiles were identified
Wider environment	Hindrance and less of a hindrance	• Two items (see upper two rows in Table 49) • The scores were added to give a possible range from 2 to 10 • The scores were ranked in ascending order • Lower and upper quartiles were identified

The results of chi-square test of association with its significance value are shown in Table 88 below (see Appendix 6 for the SPSS outputs).

Table 88: Testing the association between software use in teaching and the variables in the first column (df = 1)

	Chi-square	p-value (at 0.05 level)	Evidence of an association
Subject specialism	49.852	0.000	Yes
Gender	0.266	0.606	No
Teaching experience	0.071	0.790	No
Pedagogical beliefs	4.411	0.077	No
Access	12.087	0.001	Yes
Training	5.554	0.018	Yes
Support	9.988	0.002	Yes
Confidence	1.750	0.186	No
Competence	13.930	0.000	Yes
Curriculum	36.089	0.000	Yes
Assessment	36.191	0.000	Yes
Time	33.278	0.000	Yes
Overreliance on software	20.755	0.000	Yes
Epistemic value	11.768	0.001	Yes
Teaching value	28.542	0.000	Yes
Motivational value	10.873	0.001	Yes
Wider environment	12.476	0.000	Yes

Table 88 shows a statistically significant relationship between each of subject specialisms, access, training, support, competence, curriculum, assessment, time and wider environment and the use of software in teaching. On the other hand, Table 88 also shows that gender, teaching experience, and confidence were not significantly associated with the use of software. Beliefs about teaching were more complicated to assess. Pedagogical beliefs were not significantly associated with the level of use, but beliefs about software, namely, overreliance, epistemic value, teaching value and motivational value, were all significantly associated with the level of software use. These kinds of tests give indications of an association, but do not tell us the direction of the association between the variables. Nor should we rule out an association as likely if it is not statistically significant. For example, section 2 pointed at an association between beliefs about teaching even if this is not shown to be statistically significant. My argument remains that many of the significant variables are related to the lecturer's subject specialism; for example, the curriculum, access and the wider environment are very different for computational specialists.

Chapter 6 Discussion

As mentioned in Chapter three, this is a large-scale mixed-methods study within a post-positivist tradition. This study sought to examine how and why mathematics lecturers at Saudi universities use software for teaching. Using the terminology of Teddlie and Tashakkori (2006), the overall design of this research can be described as a concurrent mixed-methods two-strand design. This means that the research involved two relatively independent phases (two-strand): quantitative and qualitative. These two phases yielded two forms of data: qualitative and quantitative. Data were collected and then analysed independently. Data analysis was conducted separately and integration occurred at the data interpretation stage, i.e. within this chapter. The findings of the two phases are integrated by comparing the two findings. The two findings are cross-checked against each other: they can be consistent with each other (i.e. agree with each other); inconsistent with each other (i.e. disagree with each other); or complement each other (i.e. one source provides more insight into the other) (an example of a similar approach is given by Hammond and Wiriyapinit 2005). The integrated findings are then cross-checked against the wider literature.

This study consisted of two phases. In the first phase, qualitative data were collected from lecturers of mathematics. A total of 18 lecturers from 2 mathematics departments at 2 major universities in Saudi Arabia were interviewed individually in their offices. The interviewed lecturers were chosen to cover all main research interests in mathematics (pure, applied and computational mathematics) and statistics. An interview schedule was prepared containing three main themes: the use of software (including LMS), rationale for why software was used in teaching university-level mathematics and rationale for not using software in teaching university-level mathematics (Chapter 4).

The second phase utilized a quantitative approach—a cross-sectional questionnaire administered to lecturers of mathematics and statistics at eight well-established state universities in Saudi Arabia. The items in the questionnaire examined how lecturers with research interests in pure, applied and computational mathematics, and statistics used software packages in their teaching, and the rationale for ICT use (Chapter 5).

The backgrounds of the 151 lecturers who responded to the questionnaire were diverse in terms of the number of years in teaching and the range of courses they were teaching at the time of the study (the spring term of 2012). There were representatives of all three major branches of mathematics (pure, applied and computational mathematics), as well as statistics. The respondents taught mathematics and statistics as well as introductory courses for non-specialist mathematics students. Most lecturers taught across year groups, though some taught only third and fourth year students. Most of the respondents to the questionnaire reported that they had used software when they were students and they were, to varying degrees, users of software in their research.

In terms of gender, all the interviewed lecturers were male, as was the vast majority of the respondents to the questionnaire. This was for two reasons: first, for cultural reasons I only had face-to-face contact with male lecturers; and second, most lecturers were male as some courses in the female sections were taught by males through close-circuit television. An estimate based on e-mail addresses available on the universities' websites suggests that there were around 80 females in the population, suggesting that females were under-represented, but not unrepresented, in the sample.

6.1 Addressing the five research questions

The previous two chapters presented a detailed analysis of both the qualitative and quantitative approaches. The purpose of this chapter is to integrate the findings from the two phases and to relate them to the wider literature. These findings will be discussed in the context of answering the following research questions.

RQ1: How, and to what extent, do lecturers use mathematics software in the teaching of university-level mathematics courses?

RQ2: What is the context in which lecturers use ICT in the teaching of university-level mathematics?

RQ3: Do particular individuals or groups of mathematics lecturers use software more than others?

RQ4: What encourages/motivates lecturers to use software in the teaching of university-level mathematics courses?

RQ5: What discourages/constrains lecturers from using software in the teaching of university-level mathematics courses?

RQ1: How, and to what extent, do lecturers use mathematics software in the teaching of university-level mathematics courses?

The interview data showed that despite the availability of ICT facilities including mathematical software at both universities, the use of chalk and board was the dominant ‘technology’ used in the teaching of mathematics courses. The responses to the questionnaire indicated that more than half of the respondents reported using the presentation software PowerPoint when presenting their lectures, and a slightly lower number reported using a smart board when teaching.

Lecturers used software mainly in computational mathematics and statistical courses, while in other courses, particularly calculus courses, software was used occasionally by lecturers, using projection systems, for rapid calculations or to clarify concepts using the graphical capabilities of the software. There were no online courses offered through the LMSs in both universities. With regard to the questionnaire, the majority of respondents (about 73%) (Table 28 in Chapter 5) reported varying degrees of mathematical software use, while about 27% reported they had never used any such software. The findings showed that mathematicians were diverse in the percentage of lectures in which they used software; nearly 44% of the respondents were 'no/low' users of software (they used software in no more than a quarter of their lectures), while about 34% were high users (they used software in 50% or more of their lectures). In the middle were users who used software in a range between more than or equal to 26% and no more than 49% of their lectures. In addition to the use of mathematical and statistical software, respondents reported using other types of ICT such as PowerPoint and smart boards. Thus, the results of this study suggest that a large proportion of mathematics lecturers used software and other ICT tools for teaching, but in a restricted fashion.

The findings here show differentiated take up, as does the literature. For example, Lavicza (2010) in his international (US, UK, Hungary) survey of mathematical lecturers shows quite high use of CAS by mathematicians in teaching, while Hosein Aczel and Clow (2006) in another international (UK, US, Australia, New Zealand) survey of mathematical lecturers who were teaching linear programming, a computational mathematics course, show quite low use. The key contribution of this study is to show differentiated use: software was used heavily in the teaching of statistics and computational mathematics courses, while its use was very limited in the teaching of pure and applied mathematics courses.

Regarding the teaching settings in which software was used, the interviews showed that statisticians used statistical packages in their lectures using the projection systems and presentation software as well as in the computer labs. Students in statistics courses were required to do their coursework using software in the laboratory, and homework projects that involved the use of software were also assigned. As far as mathematics courses in which software was used, the interview findings showed that lecturers introduced the software for teaching purposes (usually using presentation devices) and students were then asked to do homework assignments that involved the use of software (Chapter 4).

The questionnaire findings complement the interview data. Most respondents to the questionnaire reported that they used software in the lecture room using projection systems; the majority reported assigning homework that required use of software; and a sizable minority mentioned that they used software packages in a computer lab. In terms of the type of software packages used for teaching, it was found from the interviews that Mathematica, MATLAB and Maple were the three most frequently used software by mathematicians. Minitab, SPSS and STATISTICA were the three most commonly used statistical software mentioned by the statisticians in the sample. These findings agreed with the questionnaire findings. The spreadsheet software Microsoft Excel was frequently mentioned by both mathematicians and statisticians in both the interviews and questionnaire data. The findings here are very consistent with Buteau *et al.* (2010) and their review of 326 papers on the use of CAS in post-secondary mathematics education.

As discussed further when looking at encouragers for using software, in terms of purposes, fast calculation (e.g. symbolic manipulation and numeric computation) was the most frequently mentioned purpose by respondents. The second-most frequently cited purpose for use was to help students visualize mathematical objects (e.g. graphs, geometric shapes). This was followed by the use of software for a programming language. All of the statisticians, as well as some mathematicians in the sample, reported using software packages for statistical analysis purposes. The findings outlined above are consistent with what Buteau *et al.* (2010) found as the most widely reported purposes of CAS in teaching post-secondary mathematics courses.

In terms of assessment, the interviewees indicated that some of the questions in examinations required statistics students to use statistical packages and exams were held in computer laboratories. In contrast, mathematics students were assessed through written examinations, in which students were not allowed to use software, although in some courses students were allowed to bring basic calculators and their use was expected. In one of the two universities covered by the qualitative phase, an online homework system for calculus courses had been developed. In computational mathematics courses at both universities there were homework assignments that involved the use of software. The literature shows assessment to be a crucial issue for many mathematical lecturers and it is clearly a constraint in this study, as will be discussed later in this chapter.

As far as LMS, Bb was used by lecturers in both universities covered by the first phase of the study. The interviewees mentioned that LMS was mainly used to make general announcements, to connect with students via e-mail or to post course-related materials. Overall, the use of the VLE was quite high, with only 23% reported not having used it. The most frequent use reported by the respondents to the questionnaire was publishing lecture notes and posting support material such as past exam papers. As we can see, the two findings are consistent and both suggest that communication was mainly one way, lecturers to students. This is an area covered sparsely in the literature about mathematics teachers, but the constraints of LMS in higher education are well covered (e.g. Blin and Munro 2008). As seen, the use of VLEs by those lecturers did not transform their teaching practices. They primarily used VLEs to support the transmission model of teaching, whereas activities that encouraged collaboration or reflection, such as journals and wikis, were rarely promoted.

RQ2: What is the context in which lecturers use ICT in the teaching of university-level mathematics?

With regard to access to ICT, it was found from the interviews, and confirmed by direct observation, that lecture halls in the two universities were all equipped with blackboards (or whiteboards), overhead multimedia projectors and e-podiums (lecterns). An Internet connection was available throughout the two campuses for all staff and students. LMS were also available. These findings were confirmed by the questionnaire data, which showed that nearly all the respondents reported that projection systems were available in most lecture halls. Moreover, the questionnaire results showed that the majority of the respondents felt that it was not difficult for them to schedule a class in a computer lab, though a sizable minority disagreed. Most respondents felt they had adequate technical support, but around a quarter of the respondents disagreed. However, the fact that about 7% of the respondents taught in lecture halls that lacked projection systems indicates that there is still a lack of facilities at some universities. This may be due to the fact that the Saudi higher educational system is structurally and financially highly centralized. All universities are financed through the state budget. In the past few years, there has been a steady increase in government funding for improving the existing infrastructure of universities, including the ICT infrastructure and facilities, alongside the construction of new campuses for newly established universities. Some of these campuses have been completed and others have not. The findings here agree with Alkhurbush (2011), who showed that staff and students in Saudi universities generally have good access to ICT, though there are some gaps.

Topics were predetermined in all mathematical and statistical courses at the university level. Lecturers did not have the freedom to change topics, or to propose a change in the textbooks unless they received approval from a specialized committee and went through a specific procedure. The undergraduate mathematics programs offered courses in several areas of mathematical sciences, including pure, applied, computational mathematics, and statistics. As to access to software packages, it was found from the interviews and direct observation that several mathematical and statistical software packages were available (e.g. MATLAB, Maple, Mathematica, SPSS, Minitab and STATISTICA) in the first phase of the study. In addition, general programming languages (e.g. Fortran, C, C++ and Visual Basic) and Microsoft Excel were available in both departments. The data obtained from the questionnaire further confirmed that there was good access to major mathematical and statistical software packages at most universities. The majority of the respondents to the questionnaire reported that they had good access to the software packages they needed for teaching. Only about 14% stated that they did not have good access to the necessary software. These commercial software packages have symbolic, numeric, graphical, computational and statistical capabilities that can facilitate procedural functions in most of the mathematical courses at the university level. In addition to the wider availability of the above commercial mathematical and statistical software, the findings showed that there were opportunities to use free software (i.e. software that can be accessed online free of charge, such as GeoGebra) and free online platforms such as Wolfram Alpha, which encompasses many of the computational capabilities of the commercial software. These findings suggest that there was overall quite good access to both licensed and free software.

Further, most respondents to the questionnaire reported participating in training workshops on the use of technology in teaching; these workshops were held in mathematics departments, in the IT services at universities or outside universities. However, these workshops were mainly for the general use of e-learning, including the use of VLEs, and not specifically tailored to the use of mathematical software. My earlier literature review (Chapter 2) stressed the need for lecturers to engage in CPD and to consider how technology could be used in the context of the specific lessons they teach (e.g. Barzel *et al.* 2005).The fact that the vast majority of respondents in this study were willing to attend workshops was an indicator that mathematicians in principle are not opposed to the use of technology in teaching. In particular, one of the interviewed lecturers reported giving a workshop to the faculty members of the mathematical department on how to integrate software into mathematics teaching in calculus courses. He asserted that the attendees were appreciative and that they were calling for more such workshops.

All of the above indicate a consistency and complementarity between the findings obtained from the interviews and the survey. Both sources of data suggested that there was quite good access to software, but clear gaps as well. They also indicated that the difficulty of access at some universities and the lack of appropriate training may be obstacles to the use of mathematical software in teaching.

RQ3: Do particular individuals or groups of mathematics lecturers use software more than others?

Statisticians and computational mathematicians were more likely to be users of software in teaching because they were teaching courses which require the use of software, namely computational mathematics and statistics courses. All of the interviewees pointed out that software was used as a requirement in computational mathematics and statistical courses (Chapter 4). In such courses, the interviewees said that the course description specified that lecturers must use software. This was confirmed by examining the descriptions of the courses offered in the two departments of mathematics. In other courses, especially in first year and second year courses (e.g. calculus courses), the interviewed lecturers reported that software was used sometimes as a mathematical aid, but not as an essential part of these courses.

These findings were confirmed by the questionnaire data. The chi-square tests indicated a significant association between respondents' main research interests (subject specialism) and their level of use of software in teaching. It is very likely that statisticians and computational mathematicians used software more often in teaching because they were teaching courses that require the use of software (for example, numerical analysis, in which computational techniques are applied using software to solve a wide range of problems). Perhaps, then, as they were familiar with, and habituated to, using software, they were more likely to use it when teaching other courses, such as calculus courses. In contrast, pure mathematicians were less likely to be users of software as they focused on abstract and mostly theoretical concepts.

As shown in Chapter 5, at various stages in the questionnaire analysis the findings were broken down by mathematics subject specialisms. For example, cross-tabulation analyses showed that computational mathematicians and statisticians were much more likely than pure mathematicians and applied mathematicians to use software in lecture rooms and computer labs, and to assign homework that required the use of software (Chapter 5). Interviews and questionnaire data were consistent in strongly indicating that the lecturers who taught statistics and computational mathematics courses used software more often in teaching than lecturers who taught courses that belonged to other branches of mathematics. This is one of the key findings of this study and is an important contribution to the literature. This breakdown between computational mathematics and statistics on the one hand, and pure and applied mathematics on the other has, to the best of my knowledge, not been discussed at any length previously in the literature. Yet this breakdown appears extremely important as it shows the context in which the decision to use software is more important than lecturers' individual beliefs (e.g. lecturers' beliefs about the appropriateness of using software at the undergraduate level and whether or not such use at this stage would help or hinder students' learning), though neither should be seen as independent of the other. So what explain this differentiation? As discussed, computational mathematics and statistics lecturers have the use of software built into their syllabus, but why did this come about? One can only speculate, but one reason might be that software use is not in-ground into the very notion of 'doing' pure mathematics in the same way as, say, SPSS is into 'doing' statistics. This is evidenced in the way that pure mathematicians in the sample talked about the study of proofs (e.g. A2 and B1) and were not reliant on the use of software.

In the literature review chapter, it was mentioned in Lavicza's (2010) international survey that the use of CAS in research was the most influential factor influencing mathematicians' decisions to use CAS in teaching. However, the fact that nearly all respondents (96%) in this study were users of software in their research, compared with about 73% who said they were users of software in teaching, indicates that the mere use of software in research was not a strong enough predictor influencing lecturers' decision to use software in teaching. Instead, the findings in this study concluded that the respondents' main research interests (used as an indicator to which area of mathematics they identified with), and not just the use of software in the research, was the most influential factor on lecturers in relation to their use of software in teaching.

From the questionnaire data (Chapter 5), it was found that the respondents who held constructivist views of the teaching and learning of mathematics (e.g. 'lecturers should facilitate learning rather than teach directly'; 'students should construct many of their own math problems'; 'it doesn't matter whether students get the right answers as long as they understand math concepts') came mostly from the computational branches of mathematics. They were mostly users of software in their teaching, albeit to varying degrees, and they showed a more positive outlook towards the use of software. They thought that software use helped students to understand mathematics better and helped them more in explaining mathematical concepts (see Chapter 5). This group of respondents did not believe that the use of software distracted students from understanding mathematical concepts, and they agreed that all lecturers should be using software at times in their teaching. This suggests an association between beliefs about learning and teaching mathematics, and use of ICT. However, it is not statistically significant in the same way as the association between lecturers' main research interests and their use of software in teaching.

The relationship between beliefs and use of ICT was, of course, covered in the literature with different views and mixed findings on the supposed association between beliefs and the decision to teach using ICT (e.g. Ernest 1989; Ertmer 2005; Hammond 2011; Goos 2013). In general, the findings in this study support the literature in pointing out the influence of beliefs on practice when it comes to the decision to use ICT in teaching, but at the same time such an association should not be taken for granted. In fact, two interviewed lecturers (A6 and B5) who were frequent users of software in their lectures questioned the value of the use of software, showing behaviour in contention with belief. On a wider level, although much time has been spent analysing the association between constructivism and the use of ICT (e.g. Beswick 2005; Ertmer 2005), there is no convincing argument as to why this should exist.

It was found that respondents who held more instructional views of teaching and learning mathematics (e.g. 'Lecturers should teach directly rather than just facilitate'; 'students who are not getting the right answers need to practice on more problems'; 'it is important to complete assignments exactly as lecturers planned') came mostly from the non-computational branches of mathematics. They were mostly non-users of software in their teaching, and they showed less positive views of the use of software overall. These teachers thought that ICT could distract students and hinder their understanding of mathematical concepts; they could become reliant on the software. In addition, they were opposed to directing all lecturers to use software in their teaching and they did not intend to use software in teaching in the future. Again, this is in line with the reported association between non-use of ICT and instructional pedagogy (e.g. Niederhauser and Stoddart 2001; Ertmer 2005; Laurillard 2002). Again, in this study this relationship was mediated by subject being taught.

The survey results did not suggest that there was an association between gender and the use of software in teaching (see Chapter 5). As I was not able to interview female lecturers, it was not possible to explore the gender factor and its association with the use of software in depth. So neither consistency nor complementarity can be inferred with respect to the gender variable and its association with the use of software. In the literature, ICT use is sometimes seen as 'gendered', i.e. computers are seen as appealing more to men than women. For example, as mentioned in Chapter 1, Mahdi and Al-Dera (2013) found that NFL female lecturers at a Saudi university reported less use of ICT in their teaching than their male counterparts. There was no support for such gender differences in this study.

The questionnaire did not ask about the age of the respondents as this might have been seen as intrusive. However, it did ask about the years of teaching experience, which was assumed to be an indicator of age as well as an important variable in its own right. The questionnaire data did not suggest an association between teaching experience and the use of software in teaching (Chapter 5). The interview data also did not show an association between the age of the interviewees, as apparent through the interviewees' website entries, and their use of software in teaching. As mentioned in Chapter 4, among the interviewed lecturers there were two lecturers who were strong advocates of the use of software in teaching, and were high users of software in all of their courses; one of them was a young man (B3) and the other, the most enthusiastic among all lecturers, was about to retire (A4). The findings here are consistent with Mahdi and al-Dera (2013) (see Chapter 1), who found that differences in age and teaching experience did not have a significant impact on the NFL lecturers' use of ICT in teaching. However, the general impression in the literature is that older people are less likely to use ICT compared to younger people (e.g. Neves *et al.* 2013). There is a of course a clear difference between old and new generations with respect to the contexts in which they were brought up and their exposure to technology. This brings up the recent debate regarding the supposed 'digital divide' and generational gap between 'digital natives' (those who grew up in an era of digital technology) and 'digital immigrants' (those who grew up in the pre-digital age) (Prensky 2001). While recognizing that Pernsky's ideas are important because they have drawn attention to the differences between contemporary learners and learners from previous generations, the claim that mere exposure to digital technology will lead to almost physical restructuring of the brain is very weak and without supportive evidence or data to back it up. This supposed divide between generations represents an over-simplistic and deterministic dichotomy based solely on age and exposure, while ignoring contextual differences with respect to access to technology. Such claims overlook the important role played by sociocultural and economic factors in determining the degree of an individual's access to, and ability to use, digital technology. Further, simply because younger generations are more 'connected' to digital technology does not necessarily make them more 'digitally capable' as claimed. Instead of grouping people into two opposed and mutually exclusive categories, it is perhaps more accurate to represent people, regardless of their ages, in a continuum with respect to access to and use of digital technology, showing the complexity and variability between people in these aspects. As seen, there was no association in this study between age and the use of software in teaching. This might be explained by the overwhelming importance of context in using ICT.

RQ4: What encourages/motivates lecturers to use software in the teaching of university-level mathematics courses?

The participants were asked to indicate what they perceived to be the motivating factors affecting the use of software in the teaching of mathematics and statistics courses (or the reasons behind the use of software). The major encouraging factors were both internal to the individual lecturers and environmental. The major internal encouraging factors are discussed first.

Software is good for ‘doing’ mathematics

There was a widely held belief that the use of software was good for ‘doing’ mathematics. Interviewees gave wide ranges of examples that suggested that software could enable lecturers to calculate things very quickly or produce displays that would be impossible or very difficult to do otherwise (Chapter 4). This view was echoed by the vast majority of the questionnaire respondents from different mathematical backgrounds, who overwhelmingly agreed that the use of software helps to focus teaching away from time-consuming calculations. These findings are very much in line with several studies and reviews (e.g. Stacey *et al*. 2002; Edwards 2002; Ozgun-Koca 2010; Buteau *et al*. 2010). For example, Ozgun-Koca (2010) points out that the presence of software allows curriculum developers to design curricula that focus more on concepts and less on mechanics. In this sense, due to the software, lecturers can deliver topics of a higher level of depth and complexity without wasting a lot of time on technical (or procedural) calculations, and much of the lecturer’s time can be saved for doing intellectual activities (e.g. how to interpret the results), especially when doing technical calculations was not the immediate objective of the lecture. However, Berger (2009) stresses that the use of software for speedy and automatic calculation is not always without negative consequences. For instance, its excessive use could lead to a lack of students' understanding of some of the important concepts that are often learned side by side while performing procedural computations. As will be seen later, this seemed to be a constraint on some lecturers.

Software assists visualization

The use of software to help students visualize geometric shapes, especially in 3D spaces, was the second main epistemic value to the software mentioned by lecturers in both the interviews and questionnaire. For example, an interviewee stated that he used GeoGebra because it helped his students to visualize geometric objects, and criticized mathematicians who take a more algebraic approach and ignore the visual side of mathematics. This agrees with Bergqvist *et al.* (2004), who stressed that the presence of ICT in mathematics classrooms to enable students to visualize complicated curves can cause a radical transformation in traditional teaching. For example, a teacher who wants to integrate mathematical software into teaching calculus might need to change their conventional algebraic approach to a more geometric approach based on visualization when representing mathematical objects. With regards to the questionnaire data, visualization was also the second-most frequently cited rationale, reported by 82 respondents. The findings on visualization here are very much in line with the literature, as assisting visualization was one of the most widely reported values of software use in the literature on mathematics education (e.g. Tall 1991; Palais 1999; Burrill *et al.* 2002; Giaquinto 2007; Buteau *et al.* 2010). For example, Tall (1998) explains the epistemic value of visualization and stresses that software can provide an effective means of manipulating (e.g. rotating, zooming in, zooming out) visual objects. This in turn allows for strong 'sense making' of subtle concepts at a primitive level and subsequently can provide what is described as the ‘root of knowledge’ through which the gradual growth of an established theory occurs.

Software fosters conceptual understanding

Focusing more on understanding concepts rather than on procedural calculation is an epistemic value to the software mentioned by both interviewees and questionnaire respondents. Both felt software could be used to represent mathematical concepts in multiple ways, which could facilitate understanding for different types of learners. The findings here are consistent with the literature as the use of software to quickly shift between numeric, algebraic and graphical representations of mathematical objects and to promote greater understanding of the material were frequently mentioned in the literature as potential benefits of the use of software in tertiary mathematics education (e.g. Tall 1991; Edwards 2002; Buteau *et al*. 2010).

Software engages students

Engaging, involving and making students interested, or trying to let them ‘have fun’ when learning mathematics, were all motivational value to the software mentioned by some of the ICT users in the interviewed sample. Similarly, about two thirds of the respondents to the questionnaire thought that using software in teaching mathematical courses increases interactivity, while only a small minority thought otherwise. The chi-square tests indicated a significant association between respondents’ views on motivational value of software and their level of use of software in teaching. Lavicza (2007) thinks that engaging students and trying to make them interested may be a more compelling goal for school teachers rather than university lecturers. He suggests that, unlike school teachers, university lecturers are more driven by deep-rooted mathematical principles and their strong ties to mathematics as a discipline than by pedagogical views. Yet clearly motivation of students was important enough for lecturers to use ICT in higher education too.

Having discussed the encouraging factors from a perspective of lecturers' beliefs about the value of software for teaching, learning and motivation, I now discuss the main contextual encouraging factors to the use of software in teaching university-level mathematics courses.

Good access to ICT

Having good access to equipment, training and technical support at both universities were all encouraging contextual factors mentioned by the respondents in the interviews. About 66% of the questionnaire respondents felt they had good access to software, while about 15% of respondents found software difficult to access, suggesting there may be some room for improvement. This is very much consistent with the literature. Out of all frequently cited factors that influence the decisions by teachers to use ICT in classrooms, access to ICT resources, training and technical support have always been on top (e.g. Bergqvist *et al*. 2004; Bingimlas 2009; Buteau *et al*. 2010; Hammond *et al*. 2009). However, an important point made by Jones (2004) is that the access barrier cannot be removed simply by providing hardware and software. There are other potential problems related to access, such as poor organization of resources, which leads to teachers being unable to gain access to these resources easily for the planning and preparation of lessons.

Universities encourage the use of ICT

Lecturers thought that heads of schools and university managers were pushing the use of e-learning. This is not surprising given the background, as explained in Chapter 1. In this sense they were encouraged to use ICT; however, direction and in some ways support was limited. A sense of academic freedom gave lecturers the choice to teach either with or without software. In respect to the more immediate environment, questionnaire respondents were asked whether they were encouraged by their colleagues to use software in teaching; just under half agreed, while nearly a quarter indicated that they were not encouraged by their departments to teach using software. This suggests general encouragement to use ICT, but a laissez-faire approach to implementation. These findings were consistent with previous studies, such as Goos and Bennison (2008), who reported support from colleagues and institutions' administration as one of the factors that influences the adoption of ICT by teachers of mathematics.

In some courses, software is applicable

The interviewed lecturers thought that one of the major factors affecting the use of software was that, in some courses, the use of software was very applicable (e.g. calculus in 3D) or even required (e.g. numerical analysis and statistics). Some mathematical courses require the use of software more than others. The use of software is obviously applicable in mathematical topics that involve procedural activities such as programming, computations, graphing and data analysis in statistics, as seen when considering the breakdown of groups. In some courses, software is integrated into assessment, for example, statistics students used statistical packages and exams were held in computer laboratories.

Software is easy to use

The interviewees who used software stressed unanimously that mathematical packages, especially symbolic manipulators such as Maple and Mathematica, were easy to use compared to more 'traditional' programming languages such as Fortran or C++. They stressed that the more traditional programming languages were not viewed by their students as user-friendly because of the complicated syntaxes.

In summary, the major internal encouraging factors for the use of software were: it is good for 'doing' mathematics because it offers automatic features that enable lecturers to calculate things very quickly; it assists visualization; and it makes things clearer by refocusing attention from calculation to concept and by enabling quick shifts between different representations of mathematical objects. Contextual factors included: easy access to ICT; the use of software is applicable or even essential in some courses (e.g. statistics); software is easy to use; and colleagues encourage software use.

RQ5: What discourages/constrains lecturers from using software in the teaching of university-level mathematics courses?

The participants were asked about the factors that hindered their use of software in the teaching of mathematics and statistics courses (or the reasons for non-use of software in teaching). I will first discuss the main obstacles to the wider use of software in teaching in relation to respondents' doubts about the value of software before discussing contextual barriers.

Presentations should be rough and ready (use of chalk)

Lecturers thought that when it comes to teaching mathematics, it is more natural to use chalk and board. They asserted that it may be possible in subjects other than mathematics to replace the board with other means, such as PowerPoint presentations, but when dealing with mathematical topics, writing commentary and explanations on the board was necessary. Some participants stressed that when teaching undergraduate mathematics courses, in particular, the aim is to strengthen students' mathematical background, and therefore lecturers must limit the use of software as much as possible as it may be counterproductive at this stage. One lecturer (B5) stressed the importance of spending time writing down the small details of the mathematical problem instead of posting them using a PowerPoint presentation. He emphasized that students need time to absorb what the problems are about and what they are supposed to do, and that cannot be achieved by simply displaying the problem using a projection system. Related to that is the view that was favoured by many of the interviewees and by the vast majority of the questionnaire respondents, which was that software should be used only to supplement teaching. This suggests that many lecturers favour traditional (so-called 'chalk and talk') teaching and this might also suggest that lecturers mostly view learning mathematics as a cognitive rather than 'practical' undertaking. These findings suggest that there is value in Gabriel's (2008) view that PowerPoint is a technology with some shortcomings, and it can constrain students' reasoning skills if used in a routine and passive manner. However, Gabriel stresses that PowerPoint and projective devices suit representations, such as diagrams and graphs (e.g. for visualization). What is important with PowerPoint, as is the case with any other piece of technology, is not its use as a tool per se, but how to use it constructively to achieve the desired goal of helping students with their learning and helping lecturers to keep track of the topics and activities to be covered in lectures. This suggests that the discourager here may be lack of training.

Learning mathematics requires effort

Lecturers who were interviewed for this study felt that at the undergraduate level, students need to make the effort and spend more time to learn mathematics from first principles before resorting to ready-made functions. In respect of visualization, B5, who used software extensively in his numerical analysis course, explained that when he was a student, he was initially weak in visualization but became a good 'visualizer' after years of sustained effort.

The questionnaire and interview findings showed a diversity of opinions on what should be the focus of teaching, especially in the early stages of university education, and whether the use of software may help or harm students at this particular stage. Overall, there was shared concern among the interview and questionnaire respondents as to the wisdom of using software at the university-level, and uncertainty as to the consequences of such use.

These findings are in line with the ICMI reports (e.g. Maschietto and Trouche 2010) in that the impact of the use of technology in teaching mathematics should not be taken for granted, and that there have been doubts as to the positive impact of such use on students' learning. One of the challenges that remains, according to the ICMI's report, is how to achieve a balance between the use of intellectual activities (‘chalk and talk’) and ICT tools. It seems it will be difficult to reach a majority, let alone a consensus, among mathematicians on this particular issue.

It is all a ‘black box’—overreliance on it

The idea of using mathematical software as a ‘black box’ to provide answers with little understanding of the mathematical ideas was a concern raised by some of the mathematicians interviewed in this study. A distinction was made between two approaches: the black-box approach and the white-box approach. In the former, the software user does not have to understand the internal workings of the software (e.g. the code used to solve an equation), and in the latter, the user has to execute the internal and intermediate steps when working with the software and he or she is able to develop the internal code. One interviewee stressed that lecturers should be careful not to use software as a black box unless they pass carefully through the first stage—the white-box approach. At the undergraduate level, in the view of another interviewee, the focus is primarily on strengthening students’ mathematical thinking, not just doing mathematics.

In the questionnaire, a majority agreed that some students may use software to provide answers with little understanding of mathematical concepts. This indicates that there is a widely shared concern that students may misuse software by using it as a ‘black box’. The belief that software may be used to provide answers with little understanding was held more strongly among no/low users of software than high users. In a related item, the respondents had very mixed views on whether using software in teaching would distract students from understanding mathematical concepts. As seen, both sources of data showed that the majority of participants were worried about students’ over-reliance on software.

The findings here were consistent with the literature concerned with the use of software as a black box (e.g. Barzel *et al*. 2005; Buteau *et al*. 2010; Ozgun-Koca 2010). For example, Barzel *et al*. (2005) introduced a criterion by which one can know whether a technological tool is useful or not in mathematics education. This criterion says: ‘the tool should not take away responsibility from its users’. In other words, the user should be in full control of the whole process, and a ‘good’ tool must not replace mathematics teachers, but should facilitate their work. In that sense, tools should not be treated as black boxes, since this would not promote the deductive processes that are essential in mathematics.

There will always be a thin line between ‘good’ and ‘bad’ use of software when learning and teaching mathematics. Some mathematicians believe that using software as a black box is ‘destroying’ students’ minds, while others dispute such a view and believe that the use of software necessitates an inherent understanding of the mathematical concepts, and that the process of using software in solving a mathematical problem is not just ‘pressing buttons’ without understanding the nature of the problem. This distinction between ‘good’ and ‘bad’ use of technology was a major issue in this study, and unless and until mathematicians and mathematics educators come to terms with how to bridge this gap between these two uses, a large group of mathematicians will remain hesitant to use software in teaching.

Now that I have discussed respondents’ doubts about the value of software, I will discuss some of the contextual problems that prevented some lecturers from using software when teaching mathematics courses.

In some courses, software is not applicable

Lecturers thought that in some courses the use of software was not applicable as they are concerned with theory, not technique. For example, the focus in pure mathematics courses is on learning the theories more than the applications. Respondents to the questionnaire showed no clear majority when asked if the courses they taught did not require the use of software. This suggests that some mathematical courses require the use of software more than others. Examples of such courses include computational courses and statistical courses.

Software use is not assessed

The results from the quantitative and qualitative data analyses suggest that assessment was a constraint to the use of software during lectures. Interviewees stated that the use of software was not assessed and software use was not allowed during examinations in most of the courses offered by the mathematics departments. Interviewees stated that in some of the introductory courses (e.g. calculus courses) students were only allowed to use basic calculators (i.e. hand-held calculators without programming capabilities) during examinations. Respondents to the questionnaire were divided on the issue of whether or not it is difficult to assess what students know if they can use software during tests.

The findings of this study agree with Buteau *et al*. (2010) and their review of 326 papers on the use of CAS in post-secondary mathematics education, and with Lavicza's (2010) international study, who both found that the most challenging issue in post-secondary mathematics was the presence of software during assessment and the difficulties of assessing what students know if they are allowed to use software during exams. The results here also are consistent with Ozgun-Koca (2010), who stressed that the issue of whether software will be allowed to be used during examinations is one of the most influential issues and is likely to affect the decision to use software. Assessment will likely continue to play a role in lecturers' decisions to use software in teaching as well as in students' interest in using software while learning, because it is natural that both lecturers and students will mainly focus on topics that will be assessed.

No time to deviate from heavy curriculum

Interviewees stressed that there was not enough time to deviate from the heavy and fixed content curriculum or to prepare teaching methods that involve the use of software due to the limited number of lectures available in a semester. They stressed that all courses in mathematics departments, especially the undergraduate courses, were coordinated with common examinations, which made deviating from the fixed syllabus even more difficult. The majority of the questionnaire respondents felt that the syllabus limited the use of software in teaching. This showed that there was consistency between the two sources of data on this issue. Curriculum demands and requirements were mentioned in the literature (e.g. Sarama et al. 1998; Goos and Bennison 2008) as a constraint to teachers' use of ICT in teaching.

Lack of relevant training

Although all of the interviewees stressed that there was easy access to ICT at the two universities covered by the first part of the study, and most of the respondents to the questionnaire indicated as well that they had good access to software, good access must be accompanied by adequate technical support and appropriate training on how to use software in line with the objectives of the curriculum. Technical support and training were issues that concerned the respondents to the questionnaire. Most reported that there was not enough support or adequate training for lecturers who wished to use software in their teaching. Lack of effective training is one of the frequently cited constraints to the use of technology in education (e.g. Ertmer 1999; Jones 2004; Bergqvist *et al.* 2004). Effective training, in this regard, should deal with lecturers' inability to decide when and how to use software in teaching. This issue is closely tied to the notion of 'orchestration' in the theory of instrumental genesis that was discussed in the literature review chapter (e.g. Barzel *et al*. 2005). 'Orchestration' here involves a process in which a lecturer guides his or her students so that they will be able to use an 'artefact' (any software) as a useful instrument (i.e. software plus a utilization scheme) used to mediate students' learning. Lecturers need to be trained through engaging in CPD that involves specific learning tasks dealing with specific topics in mathematics, utilization schemes to solve such tasks and models of productive orchestrations. Even if he or she believes in the usefulness of using software in learning and teaching, it is difficult for an individual lecturer who is qualified in mathematics and not the use of ICT to decide when and how to use software while teaching topics in mathematics if they are not properly trained to do so.

It is difficult for individual lecturers to design course materials that involve software

Some lecturers pointed out that it is extremely difficult for individual lecturers to design teaching materials that involve the use of software. In this regard, the interviewees stressed the need for more cooperation between lecturers to produce modern curricula that include the use of software. One interviewee (A4) stressed the need for collaborative work between mathematicians to produce e-materials for mathematical courses in all universities in the country, because collective work would be more effective than work by isolated individuals. A total of 38% of the survey respondents believed that it took too long to develop software-related teaching materials, while about 47% disagreed. Both interview and questionnaire data showed that some of the lecturers felt it is difficult for a mathematics lecturer who is a non-specialist in software to individually design mathematics materials that include the use of software. At the same time, these findings are in line with the previous literature (e.g. Laborde, and Strasser 2010), which stresses the need for collaborative work involving mathematicians, educators and ICT specialists for the design of mathematics courses that include productive use of software.

The prevailing culture was 'laissez-faire' in relation to the use of ICT

The prevailing culture in both mathematics departments covered by the interviews was 'laissez-faire' in relation to the use of ICT and did not facilitate new more fluid types of collaboration. Interviewed lecturers mentioned that the prevailing teaching 'technology' in the mathematics departments is the use of the board and chalk. Some lecturers reported that in their departments the focus is on research rather than teaching, as lecturers' promotions mainly depend on the research they produce more than the quality of the teaching they provide. In response to the survey, most respondents reported that most faculty members in the mathematics departments are non-users of software in teaching. This suggests that the respondents were not working in environments in which ICT was talked about and promoted. In another item, most respondents thought that only a few of their colleagues were enthusiastic about using software in teaching.

In summary, the participants in this study reported some barriers to the use of software. These internal barriers included: presentations in mathematics should be rough and ready (use of chalk); learning mathematics requires effort; concerns of an over-reliance on software; and the belief that mathematics at the university level is more about concepts than applications. Contextual barriers included: in some courses software is not applicable; lack of training and technical support; lack of time to deviate from the syllabus; software is not assessed; it is difficult for individual lecturers to design course materials that involve the use of software; and the prevailing culture in mathematics departments was 'laissez-faire' in relation to the use of ICT and did not facilitate new more fluid types of collaboration..

6.2 Using Valsiner's zone theory as a lens for lecturers' use of ICT

This section picks up from the earlier discussion on theorising the take up of ICT (Chapter 2, Section 5, pp. 71-87) by exploring the findings of this study through the lens of Valsiner's zone framework. It briefly discusses the idea of 'theory'; expands Valsiner's framework; explains how and why the framework was adapted to this particular study; and acknowledges some shortcomings in the use of the framework.

'Theory' carries different connotations (Hammond 2013), but most theories set out to draw attention to the key features of a phenomenon and explain how the phenomenon occurred and/or its consequences. A theory emphasises the important elements that drive the phenomenon and how these elements work together. Theories can vary in sophistication and scope. For example in this field of study (the take up of ICT), studies are frequently theorised by describing the 'factors that enable and constrain the use of ICT' (e.g. Mumtaz 2000; Scrimshaw 2004; and more recently, Gaffney 2010). This approach assumes that factors such as access, beliefs, CPD and self-efficacy are important in the take up of ICT. It also suggests cause and effect relationships (e.g. low access + incomplete training + unreformed curriculum = low take up of ICT). The value of this 'factors approach' (and it is of course the approach that was followed in this study) is that it explicitly addresses what is happening and why it is happening. This kind of modelling can be useful in practical and theoretical ways. For example, it highlights the actions that policy makers should take to change the situation (i.e. provide better access or more CPD). For the wider research community, modelling enables comparison across case studies and facilitates knowledge building.

Nevertheless, although the modelling of factors was found to be useful as an approach in this study, I also became more aware of its limitations once I had greater opportunity to reflect on my data and findings. In particular, I perceived two shortcomings. First, while the findings of this study revealed the importance of constraints such as access and curriculum, they also revealed that lecturers had varied stances on the use of software and that their take up was differentiated. Although the modelling of factors can accommodate differences in take up, the more significant problems are agency and lecturers' ability to exercise it. These issues are insufficiently covered by the factors approach. Second, perhaps patterns of behaviour in the use of ICT were not as predictable as they seemed: under the same circumstances, lecturers behaved differently—a difference that was not simply a matter of belief. I wanted to provide a better sense of the shifting worlds where lecturers work; the issue was not so much that a particular factor existed to encourage or discourage the use of ICT, but that lecturers were stepping in and out of contexts that were both open (they could teach in whatever manner they preferred) and constrained (they perceived little time to deviate from the specified curriculum). I wanted to examine the same data through a theory that more accurately explains the balance between agency and structure. An even better theory is one that can help me understand the factors involved in the decision to take up ICT and the consequences of that decision. This realisation drove me to review some of the theories put forward to explain the take up of ICT.

One point of reference discussed earlier (Chapter 2) is TAM. In TAM's framework, the decision (or intention) to use ICT can be explained primarily by beliefs (i.e. perceived usefulness and perceived ease of use). A weakness of TAM, however, is that beliefs are regarded both as ideas that an individual holds and ideas that operate on the individual, which will result in a particular type of behaviour. TAM also appears to decontextualize beliefs into ideas that individuals carry with them rather than ideas that are 'situated' in a work context. In this study, beliefs (or at least beliefs about ICT) were important factors in a lecturer's take up of ICT, but context (e.g. the courses that the lecturer taught) also played a major role in usage decision. Beliefs may well be ideas that are constructed from experience rather than fixed ideas. Of course, wider frameworks that take into account social contexts and purposes are available (e.g. UTAUT, see Chapter 2), but TAM and its extensions remain essentially deterministic in nature in the sense that such frameworks regard behaviours as brought about by certain conditions. In such frameworks, outcomes are considered predictable when particular causal agents are specified. This did not capture what I wanted to express.

At this stage, I reviewed Valsiner's (1997) zone theoretical model (Chapter 2) as a contrast to TAM. The attractive feature of zone theory is that although external and contextual conditions are important, they are regarded as insufficient in themselves to develop a predictable modelling of ICT take up. In such perspective, a linear model cannot represent a cause–effect system, one in which an outcome can be entirely explained as a function of chains of causes. The zone model is an explanatory framework that recognises both human agency and structure: a person is an agent who takes and creates choices in the context of enabling and constraining structures. Of course, agents are not free to do as they wish; they can only work towards the particular actions that an environment provides. As with social cultural theory more generally, an agent is constantly involved in 'importing' meanings through interpersonal communication with social others, 'processing' these meanings (in his or her intra-psychological system) and then 'exporting' these processed meanings to the domain of social actions (Valsiner 1997, p. 291).

The zone framework appears considerably similar to activity theory, but the latter tends to focus on the external component of psychological development and leaves the actor (human agency) without a central role (Valsiner 1997, p. 294).

As stated in Chapter 2 (pp. 76–82), in his study of human development, Valsiner (1997) proposed three zones: the ZFM, the ZPA and the ZPD. The ZFM covers ‘what is available (in terms of areas of environment, objects in those areas, and ways of acting on these objects) to the child’s acting in the particular environmental setting at a given time’ (p. 317), and the ZPA is described as ‘a set of activities, objects, and areas in the environment, in respect of which the person’s actions are promoted’ (p. 192). According to the above-mentioned characterisations, the ZFM can be viewed as the field within which actions are allowed by a person (actor) interacting with what is available in a particular environmental setting at a given time, while the ZPA can be viewed as the set of promoted actions (those actions are ordinarily within the ZFM) by the people around the actor to ‘guide his or her actions in one, rather than another, direction’.

Valsiner emphasises that the ZFM and the ZPA jointly form a functional system that directs an individual’s development when he or she is interacting with the elements of his or her surrounding environment and with the people in it: the ZFM keeps the person’s action within the acceptable boundaries of the environment, while the ZPA provides suggestions for specific actions (e.g. in the current study, promoting the use of the Smart Board in teaching). This description explains why Valsiner emphasises that regarding the ZFM and the ZPA as two parts that make up one ZFM/ZPA complex is a more accurate approach than separating the two zones. Valsiner uses strict versus permissive parenting styles to illustrate how the ZFM/ZPA framework functions (Valsiner 1997, p. 318). Strict parenting involves setting up a narrow ZFM with a strong ZPA, creating a heavily controlled situation for a child. Conversely, permissive parenting involves a wide ZFM with a weak ZPA, affording the child freedom for action. Valsiner does not use the theory to offer a view of an ideal parenting system but draws attention to the possible consequences of two markedly contrasting situations.

A key idea in the zone framework is that the developmental process is constrained (or bounded) rather than rigidly determined. Constraints on human actions (characterised in the zone framework by the ZFM) can be constructed by the people around a person (physical or cultural constraints), and they can be self-constraining elements attached to the person via personal reflections (e.g. one's own beliefs, cognitive thinking or emotional feeling). They can be and are often a combination of externally and internally motivated constraints, so that a constraint can be internalised and maintained even when the context in which this constraint was formed has changed.

Valsiner's framework lies in the field of ecological perception, for which he quotes Gibson (1979) approvingly: 'The affordances of the environment are what it offers the animal, what it provides or furnishes, either for good or ill… I mean by it something that refers to both the environment and the animal in a way no existing term does. It implies the complementarity of the animal and the environment' (p. 66).

In other words, a physical world in which we live exists and affordances are our perception of what that world offers. In my study, therefore ,I may find (for example) that PowerPoint presentations enable, say, the use of multimedia and slide shows, but mathematics lecturers may or may not perceive these functions as effective when teaching mathematics and may not of course perceive them at all. Furthermore, although some elements of the ZFM may be shared by all members of an organisation (e.g. the need to cover all pre-specified assessed topics when teaching a course), other elements may be specific to an individual (e.g. the perception that the use of software in learning mathematics can hinder students' understanding).

At every given moment in the course of development, the ZFM, in conjunction with the ZPA, describes only the current status of an actor's relationship with his or her environment in a particular context. The ZFM/ZPA system, however, is insufficient in itself to account for the future of an individual's development. Addressing this deficiency necessitates the third zone in this theoretical system to regulate movement from the present state to the immediate future of development for every person acting within an environmental setting regulated by a ZFM/ZPA complex. For such a goal to be accomplished, the ZPD is required. The ZPD was re-defined by Valsiner (1997) as 'the set of possible next states of the developing system's relationship with the environment, given the current state of the ZFM/ZPA complex and the system' (p. 200).

These three zones work together to direct the developmental processes for every agent acting within any environmental setting. Valsiner uses the term 'canalization' to describe how the ZFM/ZPA complex, in conjunction with the ZPD, directs the process within the ZFM-established boundaries in which an individual is allowed to act. The ZPD has a decisive role in this theoretical system because it represents a further mapping from present to immediate future at every point in the course of development. Consequently, the ZPD determines when the ZFM/ZPA system can accomplish its expected function. Valsiner suggests that although the ZPD has a personal character, it is jointly constructed by an individual and other people. However, an individual can cross the ZPD without direct help from others (self-scaffolding) (Valsiner 1997, p. 149). The ZPD is a difficult concept because it involves studying actions and functions that are not visible at the present time but will become visible (observable) in the immediate future. It is often concerned with emerging behaviour.

One of the attractions for representing development in terms of 'zones' is that it suggests a context without sharp edges: 'zones' are fluid, constantly changing and transforming. Valsiner posits that the process of development is constrained within, rather than determined by, a set of possible trajectories.

The general direction and particular limits of the canalisation of development, as structured by these three zones, enable the acceptance of variability and the observation of different possible trajectories when studying a phenomenon. This characteristic of canalisation explains why caution is important in codifying the zone framework into diagrams (e.g. Venn diagrams or other graphical representations). Diagrams may not capture the multi-linearity of trajectories or depict the variability of transformational processes from present to immediate future at every point in the course of an activity. Such depictions may mislead a reader by minimising the importance of human agency or by portraying this framework as a deterministic model. The zone theoretical framework was not established for such purpose.

The zone framework has been used particularly in the context of mathematics teaching (e.g. Blanton, Westbrook and Carter 2005; Goos 2005; Goos and Bennison 2008; Goos 2013; Hussain, Monaghan and Threlfall 2011) and learning mathematics (e.g. Galligan 2008). For example, Goos (2005) employs Valsiner's zone theory when she examines the factors that affect secondary school mathematics teachers who embrace or reject the use of digital technologies in their teaching practice. In considering teachers' professional development, Goos interprets the teachers' ZPD as a set of possibilities for development in the teachers' knowledge, beliefs, goals and practices. Goos views the ZFM as characterising the boundaries within the teachers' professional context, whose elements include student abilities, student behaviours, access to resources and teaching materials and curriculum and assessment requirements. The ZPA describes teaching approaches that may be promoted by formal CPD or by interaction with colleagues. An important consideration is that interaction with peers can fit either the ZFM (neutral interaction with peers) or the ZPA, depending on whether certain actions are promoted instead of being the results of such interaction.

As with the concept of 'contradiction' in activity theory, Goos (2013) discusses a similar concept to the zone framework. She emphasises that tensions between the elements of the three zones at a given time may lead to productive change. For example, tensions between lecturers' knowledge and beliefs (their ZPDs), professional contexts (their ZFMs) and individual goals can lead to change and development. Goos finds the zone approach helpful in analysing the alignments and tensions between teachers' knowledge and beliefs, their professional contexts and the professional learning opportunities available to them. Here, the notion of self-scaffolding as a sense of personal agency is important for a person acting within an environmental setting that is characterised by weak (or undeveloped) ZPAs. Self-scaffolding can also be a means through which the tensions between ZPD and ZPA are addressed.

Goos' study is an interesting attempt at applying Valsiner's theoretical framework in studying the professional learning of teachers (i.e. the teacher as a learner on how to use ICT in his or her profession). Goos sheds light on the complexities of the interaction between teachers, students, technological tools and other elements within the teaching–learning environment. Such interactions can also trigger tensions between teachers' knowledge, beliefs and goals, on the one hand, and some contextual elements on the other. These tensions may prompt a change in practice. However, Goos's adaptation of the zone framework is not free of difficulty. First, using the framework involves translation from one field (i.e. Valsiner's field of child development) to another (i.e. professional learning). This translation is particularly challenging because although both fields contain obvious asymmetries of power, the environment where a beginning teacher is situated is, in many cases, more complex than the environment of child development. Many beginner teachers may find it difficult to decipher if suggestions are in fact injunctions and must understand the distinction between pedagogical and organisational leadership. Their work is carried out in a constantly shifting ZFM/ZPA complex. Second, the notion of tension does not appear, as far as I can see, in Valsiner's framework or, at least, in his approach to contradiction; he does not regard tension in the same manner as Goos does. Third, a lingering sense is that Goos underplays the fluidity of the original framework and leans towards a modelling of conditions, which leads to outcomes. Nonetheless, reading Goos's papers left me with a sense that the zone framework can be productively applied to my study because it proposes very compelling ideas about the field of social activity.

Applying the zone framework to this study

In applying the zone framework, the lecturers' activity was viewed as taking place within broad but constrained ZFMs, weak ZPAs and varying ZPDs. In what follows, I will explain this characterisation in more detail.

The ZFMs were broad but constrained

The ZFMs define the set of allowable actions by each lecturer who taught at a particular mathematical department at the time of the study (2011–2012). In this sense, the idea of a zone of free movement is somewhat misleading because it reflects the presence of both opportunity and constraint. The set of possible actions is enabled and constrained (afforded) by what is available (e.g. resources) to a lecturer within the field of action (mathematics department). Lecturers' ZFMs vary with respect to access to resources (including ICT); the nature of the taught and assessed curriculum; the timetable available for teaching; structures and practices at the departmental level; and lecturers' perceptions of students' abilities and preferences.

As indicated in Chapters 4 and 5, the fields of actions (mathematics departments) provided the lecturers with a variety of objects such as overhead projectors, Internet connection, LMS and mathematical software (pp. 151-154, 190-192). Within the ZFMs existed not only opportunities to carry out teaching, but also opportunities to carry out actions in preparation for teaching and assessing students. It is useful, therefore, to view the ZFM as including the actions to be carried out within and beyond classrooms, that is the lecturers' offices, computer labs and possibly all other areas of the campus. It is also useful to treat the ZFM as both a physical and cultural space where actions and procedures may appear objective and immoveable. For example, assessment policies and curriculum content, even if these have been created by the action of 'agents' within organisations, appear real to the lecturers concerned. In this study, the ZFMs were particularly broad in that the lecturers were allowed to freely choose tools, including ICT, for teaching and teaching preparation. However, the ZFMs were also constrained in that the lecturers were required to teach from a syllabus that was regarded as fixed and content intensive; this situation denied the lecturers time to deviate from the content-heavy syllabus (pp. 177, 200, 202). They did not have the freedom to change the syllabus without obtaining approval from committees. The ZFMs also affected other people in the environment, particularly the lecturers' peers and pedagogical leaders. This circumstance gave rise to opportunities to develop communities of practice to support certain actions related to ICT, but the lecturers' work (e.g. B3 organised a workshop on using mathematical software to teach calculus topics) functioned largely as an individual enterprise (p. 179). Students can be viewed as another part of the equation; that is, they can be perceived both as sources of opportunity (e.g. their ICT skills and interest in ICT can be seen as stimuli for ICT use) and as sources of constraint (e.g. they may be resistant to change and perceived as having largely instrumental interests in learning) (p. 155).

The ZFM appeared broad in terms of what is possible, an almost excessive range of possible actions, in terms of delivery of teaching but narrowed by the constraints on the syllabus and on curriculum change. As previously discussed, this environment is selectively perceived. For example, some individuals perceived the objects in the environment as offering affordances such as communication, visualisation and interactivity, whereas others did not. Some saw the culture as offering opportunities to innovate, whereas others deemed it fixed and immovable (Chapters 4 and 5).

The ZPAs were weak in relation to the use of mathematical software

The ZPA represents actions that were promoted by the department or by the university to direct the lecturers' actions towards certain directions. The elements of the lecturers' ZPAs include all the actions that were promoted by formal professional development activities (CPD) and those that were promoted within documents and policies.

With respect to the general use of ICT, the elements that were primarily promoted were messages that encourage the use of ICT. Technology was formally promoted in policy documents from the Ministry of Higher Education (Chapter 1), and these were translated into specific institutional and departmental plans. As stated in Chapters 4 and 5, although most of the respondents reported participating in training workshops on the use of technology in teaching, these workshops were intended mainly for the general use of e-learning (including the use of VLEs) and not specifically tailored to the use of mathematical software (e.g. pp. 170, 178, 193-194). In terms of the immediate environment, the lecturers were generally encouraged to use technology, but mixed messages were communicated; for example, the use of software was, in many cases, unassessed (pp. 177-178, 201-202) and students were allowed to use only basic calculators (i.e. handheld calculators without programming capabilities) during examinations. Although most of the respondents agreed that generally good access to ICT resources (i.e. technology is promoted) existed, access to adequate technical support and appropriate training on using software in line with the objectives of the curriculum were constrained (pp. 193-194). The ZPAs were particularly weak in relation to the use of mathematical software. For example, as seen in Chapters 4 and 5, other than the required use of software (in computational mathematics and statistical courses), the interviews and questionnaire findings suggest that mathematics departments were 'laissez-faire' in relation to the use of mathematical software and did not facilitate new more flexible, 'bottom up' types of collaboration (pp. 178-179, 204-205).There was an emphasis on research rather than innovative teaching (p.178).

The ZPDs varied at pedagogical and technological levels

The clearest point about the zone of proximal development is that the ZPDs were highly differentiated; the lecturers had different levels of technological experience and perceived different kinds of benefits and difficulties in using the software (Chapters 4 and 5). The second points are that opportunities for support were limited (lecturers were working in a weak ZPA with respect to the use of mathematical software) and that a high degree of self-scaffolding was undertaken by the extended users of the technology. Some of the lecturers identified tools that were developed outside of their institutions. For example, A4 had created his own ‘cyber-classes’ in Moodle and used these for online communication before his university subscribed to an LMS (pp. 158, 163). These actions, although allowable in the ZFM, were not promoted by the university. As discussed earlier, other people may be interested in these initiatives, and colleagues’ engagement can directly influence innovators, but technology use would remain a fringe activity until it is ‘canalised’, as was the case with statistical software and, to a large extent, with the use of overhead projection.

TPCK revisited

The zone framework asks us to consider the elements in a lecturer’s ZPD. This task is important because, for example, promoting ICT application (ZPA) that is unaligned with a lecturer’s ZPD is an ineffective strategy. Looking through the lens of the zone theoretical system enables us to explain why a mathematics lecturer who is unfamiliar with mathematical software and who has never studied programming is unlikely to use software when teaching a mathematics course. Using software at this stage is beyond his or her immediate capability (ZPD). The zone framework does not tell us what crossing this gap should look like. For this aspect, I turn to Mishra and Koehler (2006).

Models such as TPCK determine the elements that require bridging when it comes to the use of technology in teaching. TPCK helpfully but not surprisingly tells us that teaching is a highly complex activity that requires three kinds of knowledge: content knowledge (CK), pedagogical knowledge (PK) and technological knowledge (TK). CK refers to knowledge of the content or subject matter to be learned or taught; PK pertains to knowledge about pedagogy (how content should be taught); and TK refers to knowledge of how to operate different technologies, including digital and communicational technologies. TPCK combines these three forms of knowledge. It provides a way of thinking about how technologies can be used to support helpful pedagogical strategies and how technology may change the nature of subject knowledge and the assessment of that knowledge. A lecturer who has a good understanding of TPCK can create thoughtful pedagogical choices for teaching. Despite the advantages of TPCK, however, it also suffers from certain shortcomings. The use of Venn diagrams suggests that we are dealing with areas of knowledge with equal standing and that can be easily defined. The proponents of TPCK suggest that knowledge can be reliably measured. Both these assumptions are highly doubtful, but TPCK remains helpful in providing a lens on teacher knowledge. In this study, the mathematics lecturers at universities are traditionally seen as CK experts because they are regarded as subject experts who are accredited with higher degrees in mathematical sciences. The lecturers' PK may be comparatively weak because they are not required to attend teacher preparation programmes or CPDs, and teaching may not be the main aim of their work. The lecturers' TK varies in accordance with their abilities to operate particular technologies.

To increase the potential for learning and development, each individual lecturer should build upon his or her prior knowledge of CK, PK and TK. For some, achieving this goal will involve acquiring ICT skills and developing personal comfort with ICT use. For others, accomplishment will entail extensive familiarisation with their students: the ways by which they learn and the errors that they make; their preconceptions and misconceptions; and how a particular class is different from others. Another requirement is to develop a portfolio of strategies for addressing all these challenges. For many, this will involve being reflective and learning from their professional experiences. It will also necessitate making personal decisions, that is, deciding on the teaching strategy that they should adopt instead of adhering to previous practice.

Examining the ZPD in relation to TPCK suggests that the ZPD is wide-ranging and highly personal. Little within the ZPA seems to recognise these two facts. Equally important is the fact that some lecturers simply do not believe that there is a ZPD to cross; they do not see valuable affordance in the use of technology and may have thoughtful reasons for rejecting such use. Hence, the ZPD is differentiated in terms of willingness to engage with technology.

Bringing the zones together

Table 89 summarises the features of the ZFM, ZPA and ZPD in the context of the professional practice of teaching mathematics courses at universities in Saudi Arabia at the time of the study (2011–2012).

Table 89: ZFM, ZPA and ZPD of the lecturers of mathematics at Saudi universities

Valsiner's Zones	**Characterisation**	**Elements of the Zone**
Zone of free movement (ZFM)	Broad but constrained	Technology: access to a variety of hardware and software in and out of teaching rooms, different perceptions of opportunity. Support: opportunities for technical and other means of support. Curriculum: assessment and other cultural practices seen as fixed. Students: different perceptions of abilities and motivation to use technology.
Zone of promoted action (ZPA)	Weak with respect to the use of mathematical software	CPD: generic ICT offered. Policies: general encouragement in documents and departmental plans. Support: services that support ICT use. Values: research output seen as more strongly rewarded than teaching. Curriculum: expectation of using software in some courses but not in others. Pedagogical support: under-developed.
Zone of proximal development (ZPD)	Highly differentiated	Knowledge, confidence and competence: varied with respect to ICT. Attitude towards ICT: differentiated perspectives on its value.

How does analysing the finding in this way help us understand the take up of mathematical software?

First and foremost, the zone framework clarifies why the take up of mathematical software by the mathematics lecturers was patchy despite the relatively good access to ICT resources and the high potential of the use of software in mathematics teaching. From the perspective of the zone framework, mathematical software is unlikely to be adopted on a large scale in mathematics teaching when lecturers work in a context that is characterised by numerous possibilities (broad ZFM), when the promotion of using mathematical software in teaching is weak (weak ZPA) and when support is not differentiated and not personalised. The framework allows us to see that when ZPAs are weak, the take up will not be directed; when ZFMs are broad, the take up is unlikely to be coordinated or effective; in the absence of personalised support, ZPDs are not easily crossed.

These observations suggest that addressing the problem of take up necessitates creating considerably strong ZPAs and narrower ZFMs and establishing goals that are attainable by lecturers. However, combining restricted ZFMs and strong ZPAs may weaken the sense of personal agency and diminish creativity. The importance of the zone framework lies not in providing blueprints for action but in determining the likely consequences of action.

Second, the zone framework helps us understand the decision to take up ICT. This decision is arrived at by selecting from possibilities and appreciating development opportunities. It is likely to involve self-scaffolding but is unlikely to grow without the enlisting of further support. It entails changes in the perception of an environment and may involve the introduction of new elements in that environment. It may be stimulated by a misalignment in practice and/or a perception of an opportunity, seeing the environment in different way but physically changing the environment too.

A reflection of the discussion above is the finding on two of the lecturers interviewed, namely A4 and B1. As stated in Chapter 4, the two lecturers taught at technology-rich universities, an opportunity that afforded them very good access to ICT even though university A was a new LMS (Bb) subscriber and in the early stage of using ICT in learning and teaching, whereas university B had been a long-term LMS subscriber. At both universities, the lecturers were free to teach either with or without the use of software (broad ZFMs). The structures and cultures of the two mathematics departments were similar. For both lecturers, the ZPAs were weak in relation to the use of mathematical software. The mathematics departments were laissez-faire in their approach to the use of mathematical software in teaching. Both departments established no formal CPD events that are designed to train lecturers on how to integrate mathematical software in their teaching. Both lecturers were constrained by curriculum and assessment requirements, as well as by a perception of students' preference for instructional methods. B1 kept his use of mathematical software to a minimum, staying in alignment with the boundaries set up by his ZFM, whereas A4 saw a potential for action that can be met by the introduction of ICT. Of note is that the ZFM that did not facilitate this particular action but was resolved by the lecturer creating his own resources in Moodle before his university subscribed to LMS. The experience of creating these resources created a gap between the other aspects of A4's practice and possibilities for development. However, the tension appeared creative; A4 taught all his courses (Calculus 2 and Linear Programming) in a computer lab where every student sat in front of a computer and accomplished his coursework online. By booking the lab, A4 was again altering the elements of his ZFM. He went on to create all his own online courses (he called them cyber-classes) in Moodle, another LMS, in which he uploaded all course materials, activities, discussion forums and assessments. He stated that his philosophy in education is based on 'learning through building'. Using all the ICT facilities and software packages available, he encouraged his students to create programmes to solve mathematical problems. Of course, the experience of tension can have different consequences, and the other lecturers who experimented with innovations had not further pursued change because of structural conditions. Nevertheless, A4's case demonstrates the decisive role of agency.

The zone perspective helps us determine how an environment may appear to a lecturer, alerts us to the fact that lecturers see different things in their environment (ecological perception) and provides space for human agency. At the same time, it does not disregard structural influence. It recognises the complexity and unpredictability of human conduct, and although it uses the concept of zones, it does not seek to model outcomes (actions are constrained but not predetermined). The inclusion of the ZPD emphasises the centrality of the individual and enables the study of (variability) changes and developmental processes. Using the framework offers a common-sense and clear-cut explanation as to why ICT adoption is inconsistent even within environmental settings that are characterised by relatively good access to ICT resources. It discusses consequences of actions but does so without making value judgements.

In spite of these advantages, the zone framework comes with several difficulties. First, the framework was developed in one context and 'translated' into another. In particular, the context of child development arguably allows zones to be more distinctly marked, and the asymmetry of power between parent and child is more explicit than that in professional contexts. As discussed earlier, positioning those who offer pedagogical leadership—particularly at an informal level—as part of the ZFM or the ZPA is a difficult task. Methodologically, the framework is more suitable for a longitudinal approach (observing a person over time) than for the survey approach used in this study, albeit the interviews enabled a retrospectively longitudinal perspective on take up. Problems in terminology also exist: free movement does not quite capture the idea of an environment as constrained (because this is a core concept, the term 'free movement' was retained in the discussion); Valsiner's ZPA tends to contrast narrow and broad ZPAs, whereas I find the terms 'strong' and 'weak' as offering a further dimension. Perhaps the most difficult problem I encountered in using the framework is whether to view the idea of canalisation, which works very well as a metaphor, as implying a kind of probabilistic causality. I suggested earlier that a broad ZFM with a weak ZPA was not conducive to the take up of ICT, but it is not clear whether this should be a claim to a recognised 'fact' of social activity, partly because of repeated experience (a kind of proof by induction) or because of a simple appeal to intuition. Finally, the zone framework is essentially a social psychological theory; it is sociologically weak and misses the more broadly political lens for, in this case, the introduction of ICT.

Summary of chapter 6

This chapter discussed and integrated the findings obtained from the interview and questionnaire data to explore how and why lecturers use software in mathematics teaching at Saudi universities. Regarding the use of software, the findings from both sources showed that mathematicians were diverse in their use of software in teaching. They used software mainly in computational mathematics and statistical courses, while in other courses software was utilized occasionally by lecturers for running projection systems, doing rapid calculations or clarifying concepts using the graphical capabilities of the software. The questionnaire data indicated that a large proportion of mathematics lecturers used software and other ICT tools for teaching, but in a differentiated fashion. Moreover, the data showed that only students in statistics and computational mathematics courses were required to do their coursework and homework using software. In terms of assessment, the interview data showed that statistics students were assessed in the laboratory, using statistical packages, while mathematics students were assessed through written examinations, in which students usually were not allowed to use software. As far as LMS, both sources of data suggested quite high use of LMS by lecturers, mainly to make general announcements, connect with students via e-mail or post course-related materials.

The data obtained from the interviews and questionnaire suggested that mathematics departments followed a laissez-faire approach when it came to the use of software in teaching. Both sources of data suggested that although there was easy access to ICT facilities in the majority of the departments of mathematics, with the exception of computational mathematics and statistics courses, which required the use of software, the departments of mathematics did not encourage nor discourage the lecturers in relation to the use or non-use of software in teaching, but the choice was left to the individual lecturer and his or her convictions regarding the usefulness of software.

Regarding the factors that encouraged some lecturers to use mathematical software in teaching, the findings suggested that most lecturers thought software was good for 'doing' mathematics because it offered automatic features that enable lecturers to calculate things very quickly. Most lecturers felt software use assisted visualization and made things clearer by refocusing attention from calculations to big ideas, and by enabling quick shifts between different representations of mathematical objects. Some other encouraging factors included: easy access to ICT; the use of software was applicable or even essential in some courses (e.g. statistics); software was easy to use; and colleagues encouraged software use. In contrast, some participants reported some barriers to the use of software. These barriers included: presentations in mathematics should be rough and ready; learning mathematics requires effort; concerns of an over-reliance on the use of software; the belief that mathematics at the university level is more about concepts rather than applications; and in some courses software was not applicable. Additional barriers included: lack of training and technical support, lack of time to deviate from the syllabus, software was not assessed and it was difficult for individual lecturers to design course materials that involve the use of software.

The findings in this study revealed the importance of structural constraints, but also the ability to exercise agency. The three zones theory is a theoretical model that gives space for human agency, and at the same time does not ignore structural influences. Using the terminology of the three zones theory, the data in this study suggested a very broad lecturers' ZFM with weak ZPA, creating situations where the lecturers were given a very great freedom of action in teaching. This is a relatively lenient ZFM/ZPA system that involves weak ZPA in conjunction with very broad ZFM. Lecturers' very broad ZFM pointed to the academic freedoms they enjoyed at the universities. The universities set the boundaries of the lecturers' ZFM quite wide, which provided them with excessive opportunities to make personal choices (e.g. they can teach with or without the use of software) within the boundaries of this broad ZFM. Looking at these findings through the lens of the three zones theory helped demystify the take up of ICT.

The framework allows us to see that lecturers were operating within a particularly broad zone of free movement but a weak zone of promoted action so that lecturers' activity was rarely 'canalised' into using mathematical software.

Chapter 7 Summary, Conclusions and Recommendations

This is the final chapter of this thesis. It presents an overall summary of the thesis, its major findings, strengths and areas to develop, its contribution to knowledge, recommendations for practice and future research and ends with conclusions.

7.1 Summary of the Thesis and its Main Findings

The overall objectives of this thesis were to describe the use of ICT in teaching mathematics courses in Saudi universities and explore the factors that affect the take up of ICT. In particular, this thesis sought to understand how and why mathematics lecturers in well-established Saudi universities used mathematical software for teaching. For this purpose, the following research questions were developed:

RQ1: How, and to what extent, do lecturers use mathematical software in the teaching of university-level mathematics courses?

RQ2: What is the context in which lecturers use ICT in the teaching of university-level mathematics?

RQ3: Do particular individuals or groups of mathematics lecturers use software more than others?

RQ4: What encourages/motivates lecturers to use software in the teaching of university-level mathematics courses?

RQ5: What discourages/constrains lecturers from using software in the teaching of university-level mathematics courses?

In reviewing the literature (Chapter 2), I touched on a range of issues concerning mathematics as a subject matter, how it is learned and taught and the role of ICT in doing and learning mathematics. First, I discussed the nature of mathematics, the different philosophical views of mathematics, and some major learning theories and their implications for teaching practices. Next, the objectives of mathematics learning and teaching, and the role of technology in achieving those objectives, were discussed. Different classifications of ICT and various types of technological tools were covered. I went on to look at how ICT contributes to learning and teaching mathematics, and the value of rapid calculations, visualization and multiple representations was discussed. At the same time, the relatively low use of mathematical software was noted and the factors inhibiting ICT use in mathematics teaching and the potential barriers to the use of ICT were covered. Finally, three models of understanding the take up of ICT were discussed: TAM, Valsiner's (1997) three zones theory and activity theory.

Previous research on the use of software by mathematics teachers has identified a range of factors affecting take up of ICT, including: access to ICT resources; curriculum and assessment requirements; knowledge of how to integrate technology into mathematics teaching; and beliefs about the role of technology in learning, teaching and assessing mathematics (e.g. concerns about overreliance on technology, the idea of technology as a 'black box', the use of calculators in examinations and so on). However, there is an on-going debate about the balance of internal and external factors in the adoption of ICT, and whether factors related to easy access to software are more (or less) influential than teachers' beliefs.

In Saudi Arabian universities, the conditions for successful technology integration appear to be in place, including easy access to ICT, training for lecturers to use ICT tools and favourable governmental policy towards more integration of technology in education. Despite all of these encouraging conditions, Alkhurbush (2011) suggests that technology use in teaching has been very low. This calls for more research on the factors that affect the take up of ICT in higher education in Saudi Arabia.

An overview of the research methodology

This was a mixed-methods study comprised of semi-structured interviews and a survey questionnaire. Using the terminology of Teddlie and Tashakkori (2006), the overall design of this study was a concurrent mixed-methods two-strand design. This means that it involved two relatively independent phases (two strands): quantitative and qualitative. These two phases yielded two forms of data: qualitative and quantitative. Data were collected and then analysed independently. Data analysis was conducted separately and integration occurred at the data interpretation stage. Eighteen lecturers from two mathematics departments at two major universities in Saudi Arabia were interviewed individually in their offices. Further, 151 lecturers responded to the questionnaire distributed to lecturers of mathematics and statistics at eight well-established state universities in the country. The findings of the two phases were integrated by comparing the two findings. The integrated findings were then cross-checked against the wider literature.

The key findings of the study will now be briefly summarized in respect to access to ICT, use of ICT and the factors that encouraged or discouraged the use of ICT:

Access to ICT

Most lecture halls were equipped with black boards (or white boards), overhead multimedia projectors and e-podiums. An Internet connection was available throughout the campuses. LMS were also available. Major commercial mathematical and statistical software packages (e.g. Mathematica, MATLAB, SAS and SPSS) were available and easily accessed. Training workshops were mainly for the general use of e-learning, including the use of VLEs, and not specifically tailored to the use of mathematical software.

Use of ICT

Lecturers varied in the percentage of lectures in which they used software. However, the overall picture was that a large proportion of lecturers used software and other ICT tools for teaching, but in a restricted fashion. One key finding of this study was that lecturers who taught statistical and computational mathematics courses used software in teaching more often than lecturers who taught courses that belonged to other branches of mathematics. This was because the use of software was integrated into the curriculum of computational mathematics and statistics courses. Subject specialism (i.e. area of mathematics) was the most influential factor on lecturers in relation to their use of software in teaching.

Using software for automatic calculation (e.g. symbolic manipulation and numeric computation) was the most frequently mentioned purpose of using software in teaching mathematics. The second-most frequently cited purpose for use was to help students visualize mathematical objects (e.g. graphs, geometric shapes). The use of software as a programming language to implement algorithms was the third-most frequently mentioned purpose. All of the statisticians reported using software packages for statistical analysis purposes.

In terms of assessment, some of the questions in examinations in statistical courses required the use of statistical packages. In contrast, mathematics students were assessed via written examinations in which the use of software was not allowed, except for doing basic calculations.

Respondents who held constructivist views of teaching and learning mathematics came mostly from the computational branches of mathematics. They were more likely to be users of software in their teaching and they showed a more positive outlook towards the use of software. This suggests an association between beliefs about learning and teaching mathematics and use of ICT in teaching. However, it was not statistically significant in the same way as the association between lecturers' main research interests and their use of software in teaching.

Factors that encouraged or discouraged the use of software

The findings in this study revealed factors that encouraged some lecturers to use software in teaching, and also some factors that discouraged others from using software in teaching. The major encouraging and discouraging factors are shown in Table 90.

Table 90: Major encouraging and discouraging factors to the use of software in teaching mathematics

Encouraging Factors	Discouraging Factors
• It is good for 'doing' Mathematics (as a computational tool) • It assists visualization • It fosters conceptual understanding • It engages students • Good access to ICT • Universities encourage the use of ICT • In some courses, it is applicable • It is easy to use	• Presentations should be rough and ready (use of chalk) • Learning mathematics requires effort • It is all a 'black box'—overreliance on it • In some course, it is not applicable • It is not assessed • No time to deviate from heavy curriculum • Lack of specific training for lecturers • It is difficult for individual lecturers to design course materials that involve software

The thesis had a special interest in Valsiner's (1997) three zones theory as a socio-cultural framework that recognizes both structure and human agency as complementary forces that determines human actions. The findings revealed the importance of structure, but also the possibility for exercising agency in the adoption of ICT. Lecturers had a significant level of freedom to use or not use ICT in teaching, and mathematics departments followed a laissez-faire approach when it came to the use of software in teaching. However, there are explicit (or implicit) university policies, procedures, guidelines, regulations and traditions that structure lecturers' movement within acceptable boundaries in the university environment (ZFM); there are actions promoted by decision-making bodies at each university (ZPA); and every lecturer has their preferences and their own level of capability as an 'agent' (ZPD). These three zones work jointly to 'canalise' lecturers' actions and activities within the ZFM-established boundaries.

Applying the three zones theory gives insight into why some lecturers embrace, while others reject, the use of technology in their teaching practices. Within such wide ZFM and weak ZPA as in the context of these mathematics departments, the adoption of mathematical software is unlikely on a large scale and individual lecturers can exercise a high level of personal agency over their decision to use ICT.

7.2 Research Contribution to Knowledge

This thesis contributes to knowledge in the following ways:

- The thesis contributes to an under-researched area of study, i.e. the teaching of mathematics at universities in Saudi Arabia. To the best of my knowledge, there are no previous studies that have examined the use of software packages in teaching mathematics courses at Saudi Arabian universities.
- The thesis provides an overview of a field (the literature review) helpful for anyone carrying out research in this area in the future.
- The study shows that the factors of access, training and support, curriculum, assessment, time, stance on software, competence, and wider environment influence the take up of mathematical software in teaching mathematics courses at universities. These factors were either internal to the individual lecturer or environmental (contextual). These factors are explored in depth and their consequences discussed.
- The findings of this research revealed that identification with a branch of mathematics (subject specialism) was a key factor in determining the lecturers who are likely to be users (or non-users) of software in teaching. This is one of the key findings of the study and an important contribution to knowledge. This breakdown between computational mathematics and statistics, on one hand, and pure and applied mathematics, on the other, has, to the best of my knowledge, not been discussed at any length previously in the literature. Yet this breakdown appears to be extremely important as it shows the context in which the decision to use software is more important than the lecturer's

agency, though neither should be seen as independent of the other. The study is not simply saying that subject specialism is important but that other 'factors' in the take up of ICT need to be seen through the lens of subject specialism.

- The theoretical contribution of this research is to draw attention to the limitation of the factors approach to ICT and show the value of adapting Valsiner's (1997) zones theory as a theoretical lens to understand and interpret the findings of the research. This has not been used extensively before and has not been used in the context of high and low take up. The thesis has too a particular focus on self-scaffolding and affordances which has not been discussed in depth in other application of Valsiner in this field. The value of the framework is shown in particular in addressing the agency-structure dualism, focusing on the actions carried out by individual lecturers as 'agents', who make choices either to use or not use software in teaching, in the context of constraining and enabling 'structures'. This contributes to a much wider debate in social research. The zones theory is a coherent attempt to capture agency with an understanding in social cultural settings. This makes it a useful approach and one that may be adopted by researchers in the future.
- The study demystifies the debate about ICT and mathematical software. This debate has been dominated by the question: why do not teachers use technology more? From a zone perspective, there is no mystery and it is time to move on. The study rejects the automatic assumption that ICT is a good thing and takes seriously the objections which some teachers have towards its use. Nor is it not assumed that the use of ICT is transformative.

- The findings serve to reinforce a general observation that the take up of ICT is underdeveloped for the teaching and learning of mathematics.

- The study contributes to the overall discussion of the role of theory in researching the use of technology.

7.3 Strengths and areas to be developed

This study is important for the following reasons:

- This study contributes to the mathematics education literature concerning the take up of software at the university level. This study makes a particular contribution by documenting the use of technology and exploring mathematics lecturers' views on the factors that encourage or discourage the take up of ICT in mathematics teaching.
- This study is timely, especially with the wider availability of software packages and the huge levels of investment going into ICT infrastructure in Saudi Arabia, and indeed in many other countries.
- This study contributes to addressing a gap in the literature by reporting on software use in teaching mathematics courses at Saudi Arabian universities, thus recognizing that most literature is written in English-speaking contexts.
- This study is broad and involves surveys and in-depth interviews. The breadth of the data collection and the use of mixed methods establish the credibility and dependability of the findings.
- This study has value for use in practice. Indeed, all of the interviewees and many of the surveyed lecturers requested a report of the findings of this research. This will provide them with a clearer picture of the current state of technology use in mathematics teaching at Saudi universities and an account of what the use of technology looks like. The report has value for lecturers and policy makers and sets out implications for practice.
- A strength of the research is the researcher's 'positionality'. Being a Saudi national, a graduate of mathematics from a Saudi university, and now a lecturer of mathematics at a Saudi higher educational institute, I was familiar with the context of mathematics teaching at universities in Saudi Arabia. This familiarity with the higher education system in the country helped me to work more

effectively, eased the interaction with the participants and gave me greater credibility to conduct this research.

- The study is held together through an identification of factors which affect the take up of ICT, the design of data collection instruments which explore these factors, the reporting of these factors and the final critical examination of the factors approach.

However, I am also conscious of some things I would have done differently, and areas to develop:

- As seen, this study relied overly on literature that originated in Western countries. Yet, the findings of this study, especially regarding mathematicians' views and concerns about mathematics, its learning and teaching and about the affordances and constraints of ICT, were consistent with what the wider literature revealed about mathematicians from other contexts. However, I wonder if I could have explored the local context in more detail. For example, I could have explored the cultural assumptions of Saudi Arabia as a predominantly hierarchical society, compared with less hierarchical organizational cultures such as the UK, US and Australia. Hofstede's five-dimensional model (power distance, individualism vs. collectivism, masculinity vs. femininity, uncertainty avoidance vs. tolerance for uncertainty and long-term vs. short-term orientation) (Hofstede 1991) might have provided a useful lens through which the different cultural dimensions of Saudi society could have been explored.
- As regards the survey, I would have asked clearer questions about the type of students with whom software was employed and the type of courses in which software was used. I would also have rephrased the question about beliefs.
- The lack of formal observation data was one of the areas that I would address if I was given permissions to observe lectures. I did, however, visit institutions and observe facilities, and I looked at the software installed on the machines. Further, I inspected documents such as course contents, lecturers' webpages and mathematics departments' websites. I also inspected VLEs and looked at

activity, and I informally talked to students about their use of software and VLEs. In an ideal world, however, I would have liked to have observed lecturers using ICT and, equally, not using ICT.

- The scope of this study could have been expanded to include the study of students' use of mathematical software and their views on learning mathematics with software. However, because I wanted to focus on the pivotal role of the teacher in teaching with (or without) software, I left the examination of students' learning with ICT for a future study.
- Finally, although the survey covered both male and female faculties, one limitation was my inability to access the female faculties in the interview phase of the study due to the strict policy of gender segregation in education.

7.4 Implications for Practice

The findings in this study provide educators and officials in higher education in Saudi Arabia with a clear picture of the reality of ICT use by mathematics lecturers in Saudi universities. In particular, the report shows how mathematics lecturers use ICT, describes their views and attitudes towards using software technology in the teaching of mathematics at the university level and illustrates their concerns toward some of the potential risks of over-reliance on technology. It is conveyed that the adoption of mathematical software in teaching is complex and problematic. Lecturers have their own views on technology and these views are important as lecturers are at the heart of innovation. Mathematical software is useful in all kinds of ways, but it is not a ‘magic bullet’ to address lecturers’ concerns about their teaching practices.

An overarching implication of the study is that those promoting mathematical software use in higher education should not see software as a ‘thing’ but as a ‘tool’ that can be used, or not used, in different ways by different lecturers. This implies that innovation with software should be a long-term project involving dialogue and support for change. In particular, this study has various recommendations for those in different decision-making bodies in the hierarchy of higher education in Saudi Arabia, including university lecturers, heads of departments and officials in universities and in the Ministry of Higher Education, and all those who care about learning and teaching mathematics:

- The Ministry of Higher Education should provide mathematics departments with adequate infrastructure and support facilities, and ensure that there is easier access to different learning and teaching tools, including ICT [see the key finding that access was an issue (pp. 170, 232, 250), and the importance of zones of free movement (pp. 267-268)].
- Heads of departments, course leaders and curriculum designers should consider the use of ICT in the curriculum and, in particular, a greater role for ICT in assessment should be considered and promoted [see the key finding that curriculum and assessment were important factors in the take up of software (e.g. pp. 177, 179, 200-202, 232); see the findings that most teachers recognise the value of ICT (e.g. pp.197-199) but that promoted actions are broad and weak (p.269)].
- Mathematics lecturers should engage in dialogue about how to provide suitable learning environments including ICT to their students, and should pay close attention to evaluating their teaching with or without technology [see the finding that lecturers' work functioned largely as an individual enterprise (p. 179); see findings that there was not universals agreement on the value of ICT and that teachers should have free movement to set their own goals (e.g. pp. 205-206)].
- CPD should be offered for lecturers to enrich their vision of the potential of software and its role in the learning, teaching and assessment of mathematics. CPD should be action-oriented to help each lecturer to be more comfortable when dealing with software in his or her teaching, and each lecturer should be in a better position to analyse how to use software as a tool for learning. CPD should contain specific activities on how to use software in specific learning tasks that address curriculum requirements and should recognize lecturers' prior knowledge, beliefs and experiences [see findings that CPD is too generic and skills focused (e.g. pp. 178, 179, 193-194, 241); see the

findings that lecturers' highly differentiated ZPDs are not easily crossed in the absence of personalised and differentiated support (pp. 270-274)].

- Policy makers should engage in a dialogue with lecturers on how to formulate a comprehensive national policy on the use of software in the learning of mathematics in schools. This could ease the transition between formal education and higher education, particularly with regard to the use of technology in learning and teaching mathematics [see finding on promoted action (p. 269) and the calls for reforming the curriculum that included the use of software (e.g. pp. 165, 179, 200-201)].

What, ultimately, is the value of ICT in education and mathematical software in mathematics teaching? This falls to some extent outside the scope of this research, in that I have been looking at perceptions rather than trying to show that ICT works. However, the literature and the reported value of affordances such as visualization and multiple representations in the interview data suggest that mathematical software has a huge potential to positively impact students' learning. However, resistance needs to be taken seriously and respected. We know that mathematical software can be useful, we know the take up can be creative and we know the potential and limitations of the use of ICT, but we need to know more about the circumstances in which software can have a major impact on student learning. Lecturers should aspire to appropriately and effectively use ICT in their teaching. However, they should be free to limit their use of ICT if and where they can provide a coherent rationale for not using it.

7.5 Conclusion

This thesis examined how and why mathematics lecturers at Saudi Arabian universities use software for teaching. It was a large-scale mixed-methods study within a post-positivist tradition utilizing data collected from interviews and a questionnaire. The findings of this research are consistent with previous research in pointing to: access to ICT resources; training and support; curriculum, assessment and time; wider environment; lecturers' knowledge of how to integrate technology into mathematics teaching;

and their views about the role of technology in learning, teaching and assessing mathematics as key factors affecting the take up and use of ICT in mathematics teaching at universities. The findings of this research revealed that identification with a branch of mathematics was a key factor in determining the lecturers who are likely to be users of software in teaching. This thesis puts emphasis on agency-structure dualism. The study finds the three zones framework useful as it demystifies the take up of ICT. In particular lecturers were seen as operating within a particularly broad ZFM but a weak ZPA, making take up unlikely on a large scale.

On a personal note, this thesis has been the product of five years of reading, writing and thinking. When I think back on the different stages of my journey since I started my current studies in October 2009, I realize the challenges that I have faced throughout this stressful but enjoyable journey. This thesis was my first writing in the field of mathematics education, as I came from a pure mathematics background. Educational research was a completely unfamiliar territory to me, and I have faced many challenges, not least of which were the language barrier and my urgent thirst for building my knowledge in this new area.

Throughout the different stages of this journey, I have learnt about a wide range of ideas in educational research in general, and in the topic of this thesis in particular. I have learnt about research methods, theories of learning and the different philosophical perspectives that are at the heart of educational research. Through this study, I have come to understand the extent of ICT use in the teaching of mathematics courses at Saudi universities. I have come to understand the complex relationship between learning, teaching and assessing mathematics and the use of software. Although this study addressed several issues related to the relationship between mathematics education and the use of mathematical software, it has highlighted the need for further research to understand the controversial relationship between mathematics and technology.

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APPENDICES

Appendix 1

Interview Schedule for Mathematicians

I would like to thank you very much for your voluntary participation in this study. Your views are certainly very valuable and I really appreciate your participation in this research.

This study is about how and why professors and lecturers of mathematics use mathematical software in the teaching of mathematics courses at the university level in Saudi Arabia.

Conducting interviews with mathematicians like you are required to gather information for this study which is an essential part of my PhD study in mathematics education at the University of Warwick in the UK. Your anonymity is guaranteed. You will be giving the opportunity to receive a report of the findings if you like.

First About you:

1 What is your research area in mathematics?

2 How many teaching of experience you have at university teaching mathematics?

3 What are the courses you usually teach? And what are the levels of these courses?

4 What students' audience do you usually teach (i.e. math or non-math majors)?

5 Do you usually use projection technology in your teaching? Why?

6 Do you use software in your teaching? Why? (Instructional purposes and motives)

7 Can you give examples of software use from your teaching?

8 In mathematics curriculum at this department, what is the scope of software use? (Is it implemented in one, more than one course, or in all courses?)

Second about the ICT infrastructure:

How do describe the ICT infrastructure for teaching and learning mathematics in this department?

Third: Encouragers and Discouragers of the use of ICT (factors influencing software use):

1 What do you think are the barriers or obstacles, whether technical or financial or pedagogical, to better technology integration in learning and teaching university mathematics?

2 In your views, has the assessment issue been a factor when it comes to the software use in mathematics teaching?

3 Some mathematicians fear that the use of technology when learning mathematics might weaken students understanding of basic ideas in mathematics, what is your view on that?

4 How do you view the effect of software technology on mathematical learning /teaching/understanding? (Potential benefits of software in math)

5 In your view, what are the possible disadvantages of using software in teaching mathematics at the university?

6 In your view, what are the ideal situations in term of the use of software in mathematics teaching at the university? And for what instructional purposes such usage ought to be?

Finally, do you have any additional thoughts, ideas, suggestions or issues regarding ICT use in mathematics education at the university-level?

Thank you very much for your participation in this research.

Appendix 2

Dear--- (Head of department of mathematics)

I am Bader Omran Alotaibi, a PhD student at Warwick University in the United Kingdom. I work as a lecturer in King Khalid Military Academy in the Saudi National Guard and I have a scholarship from my country to pursue my graduate study. I am currently planning to come to the kingdom in the beginning of 2011 for the data collection stage of my research which is about examining the role of software in university mathematics curriculum. As a requirement, I have to conduct interviews with mathematicians and students in various mathematics departments in the Kingdom. To gather data for my research, I have to have permission from heads of mathematics departments. So, please I need your assistance in getting this permission. Please indicate your approval of this permission by signing in the form below and returning it to this email address, **{** HYPERLINK "mailto:b.o.alotaibi@warwick.ac.uk" **}**, in your earliest convenience. This letter also serves to inform you that all the information gathered will be used solely for research purposes and that the anonymity of all is guaranteed.

I trust that you will kindly grant me this permission in conducting my research.

Thanking you very much for your help.

Yours sincerely,

Bader Omran Alotaibi

I, (   ) give permission for Mr. Bader Omran Alotaibi to conduct his research

Appendix 3 (pilot questionnaire)

The role of maths (stats)-specific software in undergraduate mathematics educations in Saudi Arabia

Introduction

Project aims: Software packages are increasingly used in the teaching and learning of university level mathematics (statistics). The primary aim of this project is to investigate mathematicians' (tacticians') views on both their conceptions and their practices of teaching undergraduate maths (stats) with software.

Definition: maths (stats)-specific software include any software packages, run on either computers or in hand held devices, that incorporates computational, symbolic, and visualization features. (For example, MATLAB, MAPLE, MATHCAD, MATHEMATICA, TI-89, TI-92, TI Voyage 200, and others). Also, statistical and operations research packages are included. (For example, SAS, Minitab, SPSS, TORA, LINDO, LINGO, STORM, and others).

Confidentiality: no data submitted via this questionnaire will ever be passed to a third party other than as part of an anonymous report prepared for the academic community.

Questions/comments: please contact Bader Omran Alotaibi- University of Warwick ({ HYPERLINK "mailto:B.O.Alotaibi@warwick.ac.uk" })

Thank you very much for your help in this study

1. What is your gender?

□Male

□Female

2. How many years have you been teaching university-level mathematics (statistics)?

□1-5 □6-10 □11-15 □16-20 □20-

3. To which of the following research area(s) of mathematics do you belong?

□Pure Mathematics □Applied Mathematics □Computational Mathematics □Statistics

□Operations research □Other-please specify: ----------------------

4. In average, how often do you use software in your research?

□Never □Rarely □Sometimes □Often □Always

5. Usually, what groups of students do you teach?

□Mathematics students □statistics students □mixed students from different departments

6. What is (are) the level(s) of maths (stats) module(s) which you usually teach? Please select all that apply.

□First year undergraduate courses □Second year undergraduate courses

□Third and/or Fourth year undergraduate courses □Master's courses

7. To any of the following field of mathematics belong the courses you usually teach?

□Calculus □Abstract Algebra □Linear Algebra □Multivariable Calculus □Analysis

□Topology □Geometry □Linear Programming □Differential Equations (ODE&PDE)

□Discrete Mathematics □Statistics □Probability and Stochastic Process □Operations research □Numerical Analysis and Computational Maths □Number Theory □Others (please specify:

8. Indicate your degree of agreement with each of the following statement?

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
projection systems are available for use in most lectures rooms					
Mathematical software packages (e.g. Matlab, Maple, SPSS) are generally available for lecturers and students					
The number of computer labs is sufficient for software-assisted teaching in my department					
It is not difficult to schedule class in computer lab					
Software is adequately accessible for everyday use					
Software support is available for those lecturers who need it					

9. Have you ever participated in any technology training provided by your department or elsewhere?

□No □Yes at the department □Yes elsewhere-please specify:

10. Please rank the following statements:

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
I would be happy to attend technology training workshops					
I would be happy to collaborate with my colleagues to develop courses that involve software use					

11. In a typical academic term, in what percentage of your lessons do you use software?

□Never

□25% or less

□26-49%

□50-74%

□75% or more

If your answer is 'Never', please answer the next question (12), otherwise skip to (17)

12. Please briefly explain what are the most important reasons that hold you back from using software in your teaching?

13. Which of the following software do you usually use in your teaching?

□ Matlab □ Maple □ Geometric sketchpad □ Mathematica □ MathCAD □ GeoGebra

□ MathPlus+ □ SPSS □ Minitab □ SAS □ Arena □ Tora □ Lindo □ Lingo □ Storm □ Others, please

specify:

18. In what setting does your software-related teaching generally take place?

	Never	Occasionally	Frequently	Always
Lecture room				
Computer Lab				
Homework projects				
Use computer-based software				
Use hand-held software				
Use Closed-circuit television				
Example class				
Office hours				

19. In what ways do you use software in your teaching?
I use software to:

	Never	Occasionally	Frequently	Always
Project images to illustrate concepts in lectures (Visualization)				
Encourage students to experience with software				
Encourage students to work in groups in lectures				
Assign homework for students to work on				
Develop worksheets for students to work with				
Develop an on-line tutorials for students				
Develop course materials that encourage students to work with software				

20. If you would like to add to this list, please briefly describe your way of teaching.

21. With what kinds of students' audiences do you usually use software in your teaching?
Courses design for:

	Never	Occasionally	Frequently	Always
Mathematics majors				
Statistics majors				
Sciences majors				
Computer sciences majors				
Engineering majors				
General courses for maths(stats) and non-maths(stats) majors				

22. With what level of courses do you usually use software?

	Never	Occasionally	Frequently	Always
First year undergraduate				
Second year undergraduate				
Higher level undergraduate				
Masters level				

23. Do you permit software to be used during assessment?

	Never	Occasionally	Frequently	Always
In-class tests				
Final exams				
Homework projects				
Other assessments				

<u>Your views on the factors that may influence the use of software in university maths and stats:</u>

24. Indicate your degree of agreement with each of the following statement?

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
Software syntax is too complex to cope with in class					
Most entry level classes are too large to incorporate software					
Only a few of my colleagues are enthusiastic about using software in mathematics(statistics) classes					
It takes too long to develop software-related teaching materials					
The poor mathematical skills of students in introductory courses mean there is less time for software use in class					
Software is too expensive for wide integration in mathematics(statistics) teaching and learning					
It is not worth using software in classes, because it cannot be used in tests					
Most of software are sufficiently user-friendly to be used in classes					
My department does not encourage the use of software in classes					
It is difficult to assess what students know if they can use software in tests					
The tight course schedule does not allow the involvement of technology					
Mathematical(statistical) software is not already available in my department to use					

25. From your experience, if you can think of any other obstacles hindering the proper use of technology in teaching university mathematics please do not hesitate to list them here.

26. Would you like to receive a report of this study?

□Yes □No

27. If you answer is yes to the question above, please provide your email address

28. Please let me know your overall comments and recommendations for this study?

Thank you very much for your participation

Appendix 4 (The study questionnaire)

The role of software packages in undergraduate mathematics educations in Saudi Arabia

I am working on a PhD research project to investigate mathematics and statistics lecturers' views on using mathematical and statistical software packages such as MATLAB, MAPLE, MATHEMATICA, MINITAB, and SPSS.

Your replies are treated as confidential.

Thank you very much for your help in this study

Bader Omran Alotaibi, PhD researcher at the University of Warwick
Contact details: **{** HYPERLINK "mailto:B.O.Alotaibi@warwick.ac.uk" **}**)

1. What is your gender?

□Male

□Female

2. How many years have you been teaching university-level mathematics (statistics)?

□1-5

□6-10

□11-15

□16-20

□20-

3. Please indicate your main research interest (s)

□Pure mathematics

□ Applied mathematics

□ Computational mathematics

□ Statistics

□ Others-please specify:

4. On average, how often do you use software in your research?

□Never

□Rarely

□Sometimes

□Often

□Always

5. I used software when I was a student:

□yes

□no

6. Do you normally teach

□Mathematics students

□ Statistics students

□ Introductory courses for students of different subjects

7. Do you normally teach

□ First year undergraduate courses

□second year undergraduate courses

□third and/or fourth year undergraduate course

8. Which courses are you teaching this year?

□Calculus □Abstract Algebra □Linear Algebra □Multivariable Calculus □Analysis □Topology □Geometry □ODE □PDE □Statistics□ Operations research □Numerical Analysis □Others -please specify:

9. To what extent do you agree or disagree with the following statements:

	Strongly Disagree	Disagree	Neither agree nor disagree	Agree	Strongly Agree
Projection systems are available in most lectures rooms					
It is not difficult for me to schedule a class in a computer lab when I want to					
I have access to the software packages I need for teaching					
I have access to technical support if I need it					

10. Have you ever participated in any technology training provided by your department or elsewhere?

□no □yes at the department □yes university IT services □yes outside the university

I would be happy to attend technology training workshops: □yes □no

11. In a typical academic term, in about which percentage of your lectures do you use mathematical or statistical software?

□Never

□25% or less

□26-49%

□50-74%

□75% or more

12. To what extent do you agree or disagree with the following statements about Mathematical and Statistical software?

	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
I find the appropriate software difficult to access in my university					
I think using software in teaching distract students from understanding mathematical concepts					
I don’t feel confident using software in my lectures					
I think it is better to use software only in courses that require it					
Software use enables students to become better problem solvers					
Students should focus in introductory courses on mathematics rather than learning to use software					
Students don’t like using software for themselves					
The courses I teach do not require the use of software					
Students like to see lecturers use software packages in teaching					
I don’t know how to integrate software into my teaching					
Most software is sufficiently user-friendly to be used in classes					
It is difficult to assess what students know if they can use software in tests					
Teaching students how to use software isn't my job					
Teaching is more interactive using software					
Students may use software to provide answers with little understanding of mathematical concepts					
I would like to use software more in my teaching					
I think the use of software in teaching					

undergraduate maths does more harm than good					
Software allows me to represent concepts in different ways					
I can explain concepts more easily using software					
It is important for students to get hands on practice of software					
Software should be used only to supplement teaching					
Software use helps to focus teaching away from time-consuming calculations					
All math lecturers should use software at times in their teaching					
Students learn math better with software					
It should be left up to the lecturer whether to use software or not					
Software packages are useful for doing mathematics, not learning mathematics					

13. If you never use software packages in your teaching, please say why this is

14. If you use software

How and where I use it

	Never	Occasionally	Frequently	Always
I use software in my lecture room				
I use it in a computer lab				
I assign homework which requires use of software				

I use software for

	Never	Occasionally	Frequently	Always
Visualisation (e.g. creating plots in 2D and 3D and animating them)				
Symbolic manipulations(e.g., derivatives, integrals, solution of linear equations, matrix operations, series operations, polynomials, algebraic simplification, optimizations)				
Numerical computations				
Statistical analysis				
A programing language (i.e. allowing users to implement their own algorithms)				

Please specify-

15. Which of the following do you usually use in your teaching?

Subject software: (Tick as many as apply)

□MATLAB □MAPLE □MATHEMATICA □MATHCAD □SCIENTIFIC WORK PLACE □SPSS □MINITAB □SAS □TORA □LINGO □spreadsheet software (e.g., Excel)

General software:

□Presentation software (e.g., PowerPoint) □Smart Board

Learning Management Systems:

□VLE software (e.g., Web CT, Blackboard, or Moodle) for: □Posting lecture notes □Emailing students □Discussion forums □Quizzes □Support material such as past exam papers

□setting and submitting online homework □others- please specify:

16. To what extent do you agree or disagree with the following statements

	Strongly Disagree	Disagree	Neither agree nor disagree	Agree	Strongly Agree
Most entry level classes are too large for the available computer labs					
The syllabus in the undergraduate mathematics program limit the use of software					
Only a few of my colleagues are enthusiastic about using software in their teaching					
It takes too long to develop software-related teaching materials					
The syllabus should be modified to include more use of software					
There isn't enough time to incorporate software into math curriculum					
There is too little support for lecturers who want to integrate software in their teaching					
My department encourages the use of software in teaching					
It is not worth using software in classes, because it cannot be used in tests					
There is enough training for lecturers who want to teach with software					
The majority of faculty members within the math department are users of software in their teaching					
Students do not pay attention to the use of software because it is no included in the tests					

17. Which better fits you?(Tick all that apply)

	This is more like me	This is more like me	
Mathematics involves mostly facts and procedures that have to be learned			In mathematics you can be creative and discover things on your own
Students who aren't getting the right answers need to practice on more problems			It doesn't matter whether students get the right answer as long as they understand the math concepts inherent in a problem
Students should construct many of their own math problems			It's important for students to complete assignments exactly as the lecturer planned
Mathematical ability is something that remains relatively ‘fixed throughout a person's life			All of my students would be good at math if they worked hard at it
lecturer should facilitate learning, rather than teach directly			lecturer should teach directly, rather than just facilitate

18. Do you have any further comments to make on the use of software to teach mathematics and statistics, can you think of cases in which it can be particularly helpful or unhelpful?

Thank you very much for your participation

Appendix 5

<u>Application for Ethical Approval for Research Degrees</u>
<u>(MA by research, MPHIL/PhD, EdD)</u>

Name of student: Mr. Bader Omran Alotaibi | PhD |

Project title: The role of ICT in undergraduate mathematics teaching in Saudi Arabia

Supervisor: Sue Johnston-Wilder and Peter Johnston-Wilder

Funding Body (if relevant): Government of Saudi Arabia

Please ensure you have read the Guidance for the Ethical Conduct of Research available in the handbook.

<u>Methodology</u>
Please outline the methodology e.g. observation, individual interviews, focus groups, group testing etc.

Mixed methods methodology comprising the following methods: interviews and questionnaires.

<u>Participants</u>
Please specify all participants in the research including ages of children and young people where appropriate. Also specify if any participants are vulnerable e.g. children; as a result of learning disability.

For the interviews: selected teaching staff and students in 3 mathematics departments in Saudi Arabia.
For the questionnaire: an online survey to all teaching staff in Saudi universities.

<u>Respect for participants' rights and dignity</u>
How will the fundamental rights and dignity of participants be respected, e.g. confidentiality, respect of cultural and religious values?
In written statements, I will assure all participants in the following:

- Their privacy and anonymity will be guaranteed.
- No misuse of information obtained from them.
- They will be given the opportunity to withdraw at any time without given reasons.

- They will be given the opportunity to receive a report of the results.

Privacy and confidentiality

How will confidentiality be assured? Please address all aspects of research including protection of data records, thesis, reports/papers that might arise from the study.

Pseudonyms will be used.

Consent - will prior informed consent be obtained?

- from participants? Yes from others? Yes

- explain how this will be obtained. If prior informed consent is not to be obtained, give reason:

Written consents

- will participants be explicitly informed of the student's status? Yes

Competence

How will you ensure that all methods used are undertaken with the necessary competence?

The research will be conducted under supervision, using BERA ethical guidelines.

Protection of participants

How will participants' safety and well-being be safeguarded?

There will be a firm commitment to ethical stance when working with the participants and the participants will know this is a research and associated with a university.

Child protection

Will a CRB check be needed? No (If yes, please attach a copy.)

Addressing dilemmas

Even well planned research can produce ethical dilemmas. How will you address any ethical dilemmas that may arise in your research?

Participants' universities will be anonymous. The researcher will exercise maximum caution and there is a liaison with supervisors and contact with the university throughout all stages of the research.

Misuse of research

How will you seek to ensure that the research and the evidence resulting from it are not misused?
Obtained data will not be passed to a third party other than as part of an anonymous report prepared for the academic community.

Support for research participants

What action is proposed if sensitive issues are raised or a participant becomes upset?

Participants will be reminded they can withdraw at any stage.

Integrity

How will you ensure that your research and its reporting are honest, fair and respectful to others?

It will be conducted under supervision taking a thoughtful ethical approaches.

What agreement has been made for the attribution of authorship by yourself and your supervisor(s) of any reports or publications?

Other issues?

Please specify other issues not discussed above, if any, and how you will address them.

Signed

Research student | Date
Bader Omran Alotaibi | 17/11/2010

Supervisor | Date
Sue Johnston-Wilder
Peter Johnston-Wilder

Action

Please submit to the Research Office (Louisa Hopkins, room WE132)

Action taken

☐ Approved

☐ Approved with modification or conditions – see below

☐ Action deferred. Please supply additional information or clarification – see below

Name | Date

Signature

Stamped

Notes of Action

Appendix 6

Chi-Square Tests (SPSS output)

1. Subject specialism and use of software in teaching:

Subject specialism * level of use Cross tabulation

			Level of use		Total
			no/low users	high users	
Subject Specialism	non-computational specialties	Count	57	12	69
		Expected Count	38.3	30.7	69.0
		% within specialty	82.6%	17.4%	100.0%
		% within level of use	87.7%	23.1%	59.0%
	computational specialties	Count	8	40	48
		Expected Count	26.7	21.3	48.0
		% within specialty	16.7%	83.3%	100.0%
		% within level of use	12.3%	76.9%	41.0%
Total		Count	65	52	117
		Expected Count	65.0	52.0	117.0
		% within specialty	55.6%	44.4%	100.0%
		% within level of use	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	49.852[a]	1	.000		
Continuity Correction[b]	47.217	1	.000		
Likelihood Ratio	53.734	1	.000		
Fisher's Exact Test				.000	.000
Linear-by-Linear Association	49.426	1	.000		
N of Valid Cases	117				

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 21.33.

b. Computed only for a 2x2 table

2. Gender and use of software in teaching:

gender * level of use Cross tabulation

			Level of use		Total
			no/low users	high users	
gender	Male	Count	56	43	99
		Expected Count	55.0	44.0	99.0
		% within gender	56.6%	43.4%	100.0%
		% within level of use	86.2%	82.7%	84.6%
	Female	Count	9	9	18
		Expected Count	10.0	8.0	18.0
		% within gender	50.0%	50.0%	100.0%
		% within level of use	13.8%	17.3%	15.4%
Total		Count	65	52	117
		Expected Count	65.0	52.0	117.0
		% within gender	55.6%	44.4%	100.0%
		% within level of use	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	Df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.266[a]	1	.606		
Continuity Correction[b]	.066	1	.797		
Likelihood Ratio	.265	1	.607		
Fisher's Exact Test				.617	.396
Linear-by-Linear Association	.264	1	.608		
N of Valid Cases	117				

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 8.00.

b. Computed only for a 2x2 table

3. Teaching experiences and use of software in teaching:

career * level of use Cross tabulation

			Level of use		Total
			no/low users	high users	
career	early career	Count	17	17	34
		Expected Count	17.6	16.4	34.0
		% within career	50.0%	50.0%	100.0%
		% within level of use	38.6%	41.5%	40.0%
	later career	Count	27	24	51
		Expected Count	26.4	24.6	51.0
		% within career	52.9%	47.1%	100.0%
		% within level of use	61.4%	58.5%	60.0%
Total		Count	44	41	85
		Expected Count	44.0	41.0	85.0
		% within career	51.8%	48.2%	100.0%
		% within level of use	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	Df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.071[a]	1	.790		
Continuity Correction[b]	.002	1	.965		
Likelihood Ratio	.071	1	.790		
Fisher's Exact Test				.827	.482
Linear-by-Linear Association	.070	1	.792		
N of Valid Cases	85				

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 16.40.

b. Computed only for a 2x2 table

4. Pedagogical beliefs and use of software in teaching:

Pedagogical beliefs * level of use Cross tabulation

			Level of use		
			no/low users	high users	Total
Pedagogical beliefs	Instructionalist	Count	22	9	31
		Expected Count	19.6	11.4	31.0
		% within pedagogical beliefs	71.0%	29.0%	100.0%
		% within level of use	91.7%	64.3%	81.6%
	Constructivist	Count	2	5	7
		Expected Count	4.4	2.6	7.0
		% within pedagogical beliefs	28.6%	71.4%	100.0%
		% within level of use	8.3%	35.7%	18.4%
Total		Count	24	14	38
		Expected Count	24.0	14.0	38.0
		% within pedagogical beliefs	63.2%	36.8%	100.0%
		% within level of use	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	4.411[a]	1	.036		
Continuity Correction[b]	2.777	1	.096		
Likelihood Ratio	4.289	1	.038		
Fisher's Exact Test				.077	.050
Linear-by-Linear Association	4.295	1	.038		
N of Valid Cases	38				

a. 2 cells (50.0%) have expected count less than 5. The minimum expected count is 2.58.

b. Computed only for a 2x2 table

5. Access and use of software in teaching:

access * level of use Cross tabulation

			Level of use		Total
			no/low users	high users	
Access	not easy access	Count	20	8	28
		Expected Count	13.5	14.5	28.0
		% within access	71.4%	28.6%	100.0%
		% within level of use	74.1%	27.6%	50.0%
	good access	Count	7	21	28
		Expected Count	13.5	14.5	28.0
		% within access	25.0%	75.0%	100.0%
		% within level of use	25.9%	72.4%	50.0%
Total		Count	27	29	56
		Expected Count	27.0	29.0	56.0
		% within access	48.2%	51.8%	100.0%
		% within level of use	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	12.087[a]	1	.001		
Continuity Correction[b]	10.299	1	.001		
Likelihood Ratio	12.567	1	.000		
Fisher's Exact Test				.001	.001
Linear-by-Linear Association	11.871	1	.001		
N of Valid Cases	56				

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 13.50.

b. Computed only for a 2x2 table

6. Training and use of software in teaching:

training * level of use Cross tabulation

			Level of use		Total
			no/low users	high users	
training	not enough training	Count	33	20	53
		Expected Count	28.2	24.8	53.0
		% within training	62.3%	37.7%	100.0%
		% within level of use	80.5%	55.6%	68.8%
	enough training	Count	8	16	24
		Expected Count	12.8	11.2	24.0
		% within training	33.3%	66.7%	100.0%
		% within level of use	19.5%	44.4%	31.2%
Total		Count	41	36	77
		Expected Count	41.0	36.0	77.0
		% within training	53.2%	46.8%	100.0%
		% within level of use	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	5.554[a]	1	.018		
Continuity Correction[b]	4.453	1	.035		
Likelihood Ratio	5.615	1	.018		
Fisher's Exact Test				.026	.017
Linear-by-Linear Association	5.482	1	.019		
N of Valid Cases	77				

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 11.22.

b. Computed only for a 2x2 table

7. Support and use of software in teaching:

support * level of use Cross tabulation

			Level of use		Total
			no/low users	high users	
support	enough support	Count	9	21	30
		Expected Count	15.9	14.1	30.0
		% within support	30.0%	70.0%	100.0%
		% within level of use	20.5%	53.8%	36.1%
	not enough support	Count	35	18	53
		Expected Count	28.1	24.9	53.0
		% within support	66.0%	34.0%	100.0%
		% within level of use	79.5%	46.2%	63.9%
Total		Count	44	39	83
		Expected Count	44.0	39.0	83.0
		% within support	53.0%	47.0%	100.0%
		% within level of use	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	Df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	9.988[a]	1	.002		
Continuity Correction[b]	8.594	1	.003		
Likelihood Ratio	10.186	1	.001		
Fisher's Exact Test				.003	.002
Linear-by-Linear Association	9.868	1	.002		
N of Valid Cases	83				

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 14.10.

b. Computed only for a 2x2 table

8. Confidence and use of software in teaching:

confidence * level of use Cross tabulation

			Level of use		Total
			no/low users	high users	
Confidence	less confident	Count	17	23	40
		Expected Count	20.2	19.8	40.0
		% within confidence	42.5%	57.5%	100.0%
		% within level of use	34.7%	47.9%	41.2%
	Confident	Count	32	25	57
		Expected Count	28.8	28.2	57.0
		% within confidence	56.1%	43.9%	100.0%
		% within level of use	65.3%	52.1%	58.8%
Total		Count	49	48	97
		Expected Count	49.0	48.0	97.0
		% within confidence	50.5%	49.5%	100.0%
		% within level of use	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	1.750[a]	1	.186		
Continuity Correction[b]	1.246	1	.264		
Likelihood Ratio	1.755	1	.185		
Fisher's Exact Test				.219	.132
Linear-by-Linear Association	1.731	1	.188		
N of Valid Cases	97				

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 19.79.

b. Computed only for a 2x2 table

9. Competence and use of software in teaching:

competence * level of use Cross tabulation

			Level of use		Total
			no/low users	high users	
competence	less competent	Count	15	1	16
		Expected Count	8.2	7.8	16.0
		% within competence	93.8%	6.3%	100.0%
		% within level of use	29.4%	2.0%	16.0%
	Competent	Count	36	48	84
		Expected Count	42.8	41.2	84.0
		% within competence	42.9%	57.1%	100.0%
		% within level of use	70.6%	98.0%	84.0%
Total		Count	51	49	100
		Expected Count	51.0	49.0	100.0
		% within competence	51.0%	49.0%	100.0%
		% within level of use	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	Df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	13.930[a]	1	.000		
Continuity Correction[b]	11.968	1	.001		
Likelihood Ratio	16.380	1	.000		
Fisher's Exact Test				.000	.000
Linear-by-Linear Association	13.791	1	.000		
N of Valid Cases	100				

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 7.84.

b. Computed only for a 2x2 table

10. Curriculum and use of software in teaching:

curriculum * level of use Cross tabulation

			Level of use		Total
			no/low users	high users	
Curriculum	curriculum was not an obstacle	Count	6	21	27
		Expected Count	16.9	10.1	27.0
		% within curriculum	22.2%	77.8%	100.0%
		% within level of use	17.1%	100.0%	48.2%
	curriculum was an obstacle	Count	29	0	29
		Expected Count	18.1	10.9	29.0
		% within curriculum	100.0%	0.0%	100.0%
		% within level of use	82.9%	0.0%	51.8%
Total		Count	35	21	56
		Expected Count	35.0	21.0	56.0
		% within curriculum	62.5%	37.5%	100.0%
		% within level of use	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	36.089[a]	1	.000		
Continuity Correction[b]	32.847	1	.000		
Likelihood Ratio	45.491	1	.000		
Fisher's Exact Test				.000	.000
Linear-by-Linear Association	35.444	1	.000		
N of Valid Cases	56				

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 10.13.

b. Computed only for a 2x2 table

11. Assessment and use of software in teaching:

assessment * level of use Cross tabulation

			Level of use		Total
			no/low users	high users	
Assessment	assessment was not obstacle	Count	5	23	28
		Expected Count	16.2	11.8	28.0
		% within assessment	17.9%	82.1%	100.0%
		% within level of use	15.2%	95.8%	49.1%
	assessment was an obstacle	Count	28	1	29
		Expected Count	16.8	12.2	29.0
		% within assessment	96.6%	3.4%	100.0%
		% within level of use	84.8%	4.2%	50.9%
Total		Count	33	24	57
		Expected Count	33.0	24.0	57.0
		% within assessment	57.9%	42.1%	100.0%
		% within level of use	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	36.191[a]	1	.000		
Continuity Correction[b]	33.034	1	.000		
Likelihood Ratio	42.616	1	.000		
Fisher's Exact Test				.000	.000
Linear-by-Linear Association	35.556	1	.000		
N of Valid Cases	57				

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 11.79.

b. Computed only for a 2x2 table

12. Time and use of software in teaching:

time * level of use Cross tabulation

			Level of use		Total
			no/low users	high users	
Time	lack of time was not an obstacle	Count	5	21	26
		Expected Count	15.4	10.6	26.0
		% within time	19.2%	80.8%	100.0%
		% within level of use	15.6%	95.5%	48.1%
	lack of time was an obstacle	Count	27	1	28
		Expected Count	16.6	11.4	28.0
		% within time	96.4%	3.6%	100.0%
		% within level of use	84.4%	4.5%	51.9%
Total		Count	32	22	54
		Expected Count	32.0	22.0	54.0
		% within time	59.3%	40.7%	100.0%
		% within level of use	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	33.278[a]	1	.000		
Continuity Correction[b]	30.158	1	.000		
Likelihood Ratio	38.912	1	.000		
Fisher's Exact Test				.000	.000
Linear-by-Linear Association	32.662	1	.000		
N of Valid Cases	54				

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 10.59.

b. Computed only for a 2x2 table

13. overreliance on software and use of software in teaching:

overreliance * level of use Cross tabulation

			Level of use		Total
			no/low users	high users	
Overreliance	Less overreliance	Count	6	24	30
		Expected Count	14.7	15.3	30.0
		% within overreliance	20.0%	80.0%	100.0%
		% within level of use	20.7%	80.0%	50.8%
	More overreliance	Count	23	6	29
		Expected Count	14.3	14.7	29.0
		% within overreliance	79.3%	20.7%	100.0%
		% within level of use	79.3%	20.0%	49.2%
Total		Count	29	30	59
		Expected Count	29.0	30.0	59.0
		% within overreliance	49.2%	50.8%	100.0%
		% within level of use	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	20.755[a]	1	.000		
Continuity Correction[b]	18.449	1	.000		
Likelihood Ratio	22.181	1	.000		
Fisher's Exact Test				.000	.000
Linear-by-Linear Association	20.403	1	.000		
N of Valid Cases	59				

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 14.25.

b. Computed only for a 2x2 table

14. epistemic values and use of software in teaching:

Epistemic value * level of use Cross tabulation

			Level of use		Total
			no/low users	high users	
Epistemic value	less epistemic value	Count	18	5	23
		Expected Count	12.0	11.0	23.0
		% within epistemic value	78.3%	21.7%	100.0%
		% within level of use	69.2%	20.8%	46.0%
	more epistemic value	Count	8	19	27
		Expected Count	14.0	13.0	27.0
		% within epistemic value	29.6%	70.4%	100.0%
		% within level of use	30.8%	79.2%	54.0%
Total		Count	26	24	50
		Expected Count	26.0	24.0	50.0
		% within epistemic value	52.0%	48.0%	100.0%
		% within level of use	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	11.768[a]	1	.001		
Continuity Correction[b]	9.900	1	.002		
Likelihood Ratio	12.334	1	.000		
Fisher's Exact Test				.001	.001
Linear-by-Linear Association	11.533	1	.001		
N of Valid Cases	50				

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 11.04.

b. Computed only for a 2x2 table

15. value for teaching and use of software in teaching:

Teaching values * level of use Cross tabulation

			Level of use		
			no/low users	high users	Total
Teaching values	less teaching values	Count	25	4	29
		Expected Count	15.0	14.0	29.0
		% within teaching values	86.2%	13.8%	100.0%
		% within level of use	86.2%	14.8%	51.8%
	more teaching values	Count	4	23	27
		Expected Count	14.0	13.0	27.0
		% within teaching values	14.8%	85.2%	100.0%
		% within level of use	13.8%	85.2%	48.2%
Total		Count	29	27	56
		Expected Count	29.0	27.0	56.0
		% within teaching values	51.8%	48.2%	100.0%
		% within level of use	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	28.542[a]	1	.000		
Continuity Correction[b]	25.755	1	.000		
Likelihood Ratio	31.640	1	.000		
Fisher's Exact Test				.000	.000
Linear-by-Linear Association	28.033	1	.000		
N of Valid Cases	56				

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 13.02.

b. Computed only for a 2x2 table

16. motivational values and use of software in teaching:

Motivational values * level of use Cross tabulation

			Level of use		Total
			no/low users	high users	
Motivational values	less motivational values	Count	20	6	26
		Expected Count	14.0	12.0	26.0
		% within motivational values	76.9%	23.1%	100.0%
		% within level of use	69.0%	24.0%	48.1%
	more motivational values	Count	9	19	28
		Expected Count	15.0	13.0	28.0
		% within motivational values	32.1%	67.9%	100.0%
		% within level of use	31.0%	76.0%	51.9%
Total		Count	29	25	54
		Expected Count	29.0	25.0	54.0
		% within motivational values	53.7%	46.3%	100.0%
		% within level of use	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	10.873[a]	1	.001		
Continuity Correction[b]	9.147	1	.002		
Likelihood Ratio	11.308	1	.001		
Fisher's Exact Test				.001	.001
Linear-by-Linear Association	10.672	1	.001		
N of Valid Cases	54				

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 12.04.

b. Computed only for a 2x2 table

17. wider environment and use of software in teaching:

Wider environment * level of use Cross tabulation

			Level of use		
			no/low users	high users	Total
Wider environment	less encouragement	Count	18	8	26
		Expected Count	11.6	14.4	26.0
		% within wider environment	69.2%	30.8%	100.0%
		% within level of use	75.0%	26.7%	48.1%
	more encouragement	Count	6	22	28
		Expected Count	12.4	15.6	28.0
		% within wider environment	21.4%	78.6%	100.0%
		% within level of use	25.0%	73.3%	51.9%
Total		Count	24	30	54
		Expected Count	24.0	30.0	54.0
		% within wider environment	44.4%	55.6%	100.0%
		% within level of use	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	12.476[a]	1	.000		
Continuity Correction[b]	10.615	1	.001		
Likelihood Ratio	12.999	1	.000		
Fisher's Exact Test				.001	.000
Linear-by-Linear Association	12.245	1	.000		
N of Valid Cases	54				

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 11.56.

b. Computed only for a 2x2 table