Enhancing the Teaching of Mathematically Intensive STEM Disciplines at a Tertiary Level Through the Use of Pen-enabled Tablet PCs

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For my mother.

A book, of sorts.

ABSTRACT

This thesis examines issues involved in the introduction of pen-enabled Tablet PC (penTPCs) technology in a university context, for use in learning and teaching within mathematically intensive subjects. A design based research (DBR) approach is explored, in which a conceptual framework is used to provide a theoretical and practical basis for the introduction of the technology. Lecturer and student reactions to this intervention were studied and are related to the conceptual framework, to validate the rationale for the intervention, and to suggest the design of potential ongoing cycles of future intervention. A conjecture mapping technique is used to describe the intervention design. Institutional factors that acted to either support or impede the introduction of the technology are also identified.

The core content of this thesis is contained in five international journal papers (four published, one under review) that investigate different aspects of the initial cycle of technology implementation. Data from student and staff surveys, video of class sessions, and other evidence was analysed. This revealed a generally favourable response from lecturers and students to the initial introduction of the technology, but that the usage was essentially in maintenance of traditional pedagogic approaches; the penTPC provided a functional improvement in visibility over classroom whiteboard displays, while allowing continuing use of dynamic handwritten development of material. However, additional analysis of the response data, and a review of the associated conceptual framework, suggests that another cycle of a DBR approach could investigate use of the technology in support of alternative, more transformative, pedagogic approaches.

While the thesis examines a specific case of penTPC technology introduction, the findings and DBR approach developed may also be applicable in other contexts and in the introduction of other learning and teaching technologies.

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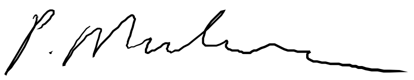
ATTESTATION OF AUTHORSHIP

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.

This thesis contains five separate articles that have either been published or have been submitted to peer-reviewed international journals for consideration for publication. My contribution and contribution of the various co-authors to each of these articles are outlined in the following section. All co-authors have approved the inclusion of the joint work in this doctoral thesis.



LIST OF ARTICLES AND CO-AUTHOR CONTRIBUTIONS

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> Tony, who was always ready with a reference, or two, that would help elucidate any topic.
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ETHICS APPROVAL

Ethical approval for the student survey, and staff surveys, video analysis and other feedback reported in Chapters 5,6,8,9 (Articles 2,3,4,5) was obtained from Auckland University of Technology's Ethics Committee (AUTEC): Ethics Application: 14/188 Pen enabled teaching and learning - Enhancing the student experience in STEM disciplines in a tertiary environment.

CHAPTER 1 / INTRODUCTION

Introduction

This thesis is concerned with the introduction of pen-enabled Tablet PC (penTPC) technology in a university. The penTPC is a Microsoft Windows device that supports handwritten input through a digital pen writing on the computer screen. The thesis investigates how the affordances of the technology might be used by lecturers to enhance learning in mathematically intensive (MI) disciplines. It also examines the institutional factors that impacted the introduction of the technology, and the aspects of the technology that influenced its acceptance by lecturers, students, and the institution.

This research study arose out of my work activities as an academic advisor in which I was involved in instigating use of the penTPC as an educational technology. However, the origins of my interest may be traced back further; to my initial undergraduate education in engineering; to computing work in this and related disciplines; to my training and work in primary education; to some 15 years of teaching applied mathematics at a tertiary level; to later work in implementing online educational technology; and the completion of a Master's qualification in online education and educational technology, online. Thus when the penTPC became available to me in 2005, the educational applications of the technology to the teaching of mathematical disciplines were immediately intuitively apparent: the penTPC brought the missing dimensions of handwritten communications, and associated thinking processes, into the educational computing environment. These elements are explored in a more rigorous, theoretical approach in Chapter 3.

While justifications from external theory and practice were used in formulating proposals for introduction of the technology in the work setting, the early developments were not initially framed in the context of a formal research-based approach. The potential to use a Design Based Research (DBR) approach emerged as offering a more structured way of analysing the project as it developed. DBR is a broad term that describes a range of approaches, and the particular form applied in this study is examined in more detail in Chapter 2.

While ideally this implementation would have occurred as an institutionally supported, planned innovation process, the reality was (as discussed in Chapter 8), it evolved as an "emergent change" (Iles & Sutherland, 2001, p. 14), with a combination of internal organisational structures, cultures and goals, and external factors, "shaping the change process by 'drift' rather than by design" (p.14).

While the issues encountered in the institutional context of this project constrained the implementation, the literature suggests that this may not be unusual: Akkerman, Bronkhorst and Zitter (2011) note that "design research is an inherently complex research approach", having "complications which arise from sustained intervention in messy situations" (p.422); they quote Engeström (2007, p. 369) as describing interventions as involving "contested terrains, full of resistance, reinterpretation and surprises from the actors". Middleton, Gorad, Taylor and Bannan-Ritland (2006) note that "a number of the conditions which have a potentially fatal impact on the enactment of a design are out of the control of the designer and, instead, are contingent upon the political and situational features of a potential application" (p. 6).

Despite a preference for carefully planned, empirically based and designed interventions, the reality may be a more chaotic environment that necessitates a more reactive, pragmatic approach. This is not to suggest the abandonment of planning and theory –

rather that the nature of this form of environment needs to be acknowledged and accounted for in the planning and conceptualisation of the intervention. The practical restrictions on the implementation of the technology in this institutional context have meant that the scope of this research has been limited at this stage to what are essentially exploratory cycles in a DBR approach; suggestions are made for the direction of further cycles, but implementation of these remain a matter for ongoing research.

A discussion of the theoretical basis of the DBR approach follows in Chapter 2. The initial exploratory stages of the intervention are formulated in terms of Sandoval's (2014) concept of conjecture mapping, as a technique for approaching a DBR project. The particular application of the DBR approach to this study is described in Chapter 3, along with an overview of the conceptual framework underpinning the overall study, and the data collected and instruments used. Chapter 3 also includes an overview of the journal articles that make up Chapters 4, 5, 8 and 9. Each of these journal papers reflects different aspects of the design implementation. A review of the initial cycle of DBR intervention is provided in Chapter 7. Chapter 8 has a slightly different focus, and investigates the institutional factors that impacted the introduction of the technology. Chapter 9 and Chapter 10 provide analysis of existing practices in resource provision and notetaking. Potential future DBR cycles, informed by this analysis, are discussed in Chapter 11. This final chapter provides a concluding overview that reflects on the general use of a DBR approach in interventions of the form described in this study.

Thesis Structural Organisation – Pathway 2

This is a thesis by publication that follows the Auckland University of Technology (AUT) *Pathway 2* Doctoral submission requirements, as detailed in the AUT Postgraduate

Handbook (AUT, 2017, p. 101). The core body of work consists of chapters based on five journal papers (four published and one under review). Each paper contains an introductory section that reviews relevant literature, discusses the research methodology, and states conclusions and indications for further research - as pertinent to the focus of the particular paper. While each paper addresses a different aspect of the research, the common general theme means that there is some overlap in content. These core paper-chapters are enclosed by introductory and concluding chapters that give an overview of the research themes, literature, and methodology, draw together overall conclusions, and suggest further directions for research.

The paper-based chapters were subject to varying journal publishing requirements for formatting, including section structure, word limits and referencing. These papers have been reformatted in a consistent style in this thesis. All citations have been presented in American Psychological Association (APA6) referencing format, and all references are combined in a single bibliography in the References section at the end of the thesis. Other minor alterations have been made (such as in use of a consistent abbreviation format), but the chapters keep the stand-alone structural consistency of the original papers. The numbering of Figures and Tables is sequential within each article/chapter, as in the original published articles; thus references to Tables and Figures are to those within the current article/chapter unless otherwise specified.

Thesis Conceptual Organisation – the Narrative

This section is intended to give a more detailed conceptual overview of the issues covered in the following chapters. Some chapters consist of individual articles that were written to be self-contained works; this section expands on the relationships between these articles, and between the articles and other chapters, to orient the reader to the overall narrative.

CHAPTER 2 / DESIGN BASED RESEARCH – THEORY AND TERMINOLOGY provides details of the underlying Design Based Research (DBR) approach, in general terms. It emphasises the pragmatic nature of this form of research, with the overall focus being on seeking (as discussed in Chapter 3) “to improve, not to prove” (Reeves, 1999, p. 19).

CHAPTER 3 / THE PEN-ENABLED TABLET PC PROJECT first discusses the introduction of the use of penTPC in the study university from the perspective of a DBR approach. It then examines the literature that relates to the development of a conceptual framework that underlies the various aspects of the study (while noting that individual Articles contain their own specific literature reviews). The chapter then includes a section that provides an overview of the various data sources and methodologies that are used in the later Articles and Chapters. Finally the chapter has a section that provides an overview of the individual articles.

CHAPTER 4 / ARTICLE 1 - THE NEW CHALKBOARD: THE ROLE OF DIGITAL PEN TECHNOLOGIES IN TERTIARY MATHEMATICS TEACHING is the first published Article, and discusses preliminary findings from a small pilot survey implementations of the penTPC technology, and a rationale for further developments.

CHAPTER 5 / ARTICLE 2 - I SEE WHAT YOU ARE DOING: STUDENT VIEWS ON LECTURER USE OF TABLET PCS IN THE ENGINEERING MATHEMATICS CLASSROOM is a second published article, and follows on from Article 1 in examining a more substantive implementation of the penTPC technology. It provides an in-depth analysis of a 2015 survey of 480 students, on their views of different presentation technologies.

CHAPTER 6 / ARTICLE 3 - MAKING THE POINT: THE PLACE OF GESTURE AND ANNOTATION IN TEACHING STEM SUBJECTS USING PEN-ENABLED TABLET PCS, the third published article, represents a change of focus, in examining specifically lecturer (rather than student) responses to the use of the technology. The study involved analysis of videos of 7 lecturers delivering classes using penTPCs, and examined how the use of the device impacted on their interactions in class, and particularly their use of gesture and annotation.

CHAPTER 7 / DISCUSSION: THE INITIAL DESIGN CYCLE reviews the previous chapters in terms of an initial DBR design cycle (in which penTPC was used to enhance delivery of material in the class room) and provides a link to the opportunities for further DBR cycles (in which the penTPC *might* be used in support of changes in practice).

CHAPTER 8 / ARTICLE 4 - INSTITUTIONAL ADOPTION OF AN INNOVATIVE LEARNING AND TEACHING TECHNOLOGY: THE CASE OF THE PEN-ENABLED TABLET PC has a significantly different methodology and focus. Rather than examining student and/or lecturer responses to the technology, it examines institutional responses to the implementation of the technology. There had been significant institutional barriers to the adoption of the technology, in spite of positive responses from students and lecturers. This article addresses critical institutional issues that need to be resolved for successful implementation of an educational technology.

CHAPTER 9 / ARTICLE 5 - HOW IS THAT DONE? STUDENT VIEWS ON RESOURCES USED OUTSIDE THE ENGINEERING CLASSROOM analyses a different aspect of the 2015 survey of 480 students. It examines student attitudes to use of different materials outside the class. The earlier articles had established that the penTPC was able to be used effectively by lecturers for classroom presentation of material, and that students would respond positively.

CHAPTER 10 / STUDENT AND LECTURER VIEWS ON NOTETAKING is a further analysis of a different aspects of the 2015 survey of 480 students and the 2015 survey of staff; this chapter examines the practice of notetaking as a core component of the traditional lecture, from both a student and lecturer perspective.

CHAPTER 11 / FUTURE DESIGN CYCLES AND CONCLUSIONS draws on the findings in CHAPTER 9 and CHAPTER 10 to suggest potential further DBR cycles in which the penTPC might be used in order to facilitate a change in delivery approaches (rather than just enhancing or maintaining existing approaches).

It identifies the potential of the penTPC to provide alternatives to the use of the lecture for classroom provision of notes, and for the provision of resources for students to use outside class and expresses these possibilities in terms of redeveloped high level conjectures.

Final comments summarise the findings and identifying opportunities for, and barriers to, further development.

The APPENDICES (after REFERENCES) contain copies of the survey forms and details of their use.

CHAPTER 2 / DESIGN BASED RESEARCH – THEORY AND TERMINOLOGY

> When I use a word," Humpty Dumpty said, in a rather scornful tone, "it means just what I choose it to mean - neither more nor less."
> "The question is," said Alice, "whether you can make words mean so many different things."
> "The question is," said Humpty Dumpty, "which is to be master - that's all."
>
> Lewis Carroll (1871)
> *Through the looking glass: And what Alice found there*

In this section I discuss the Design Based Research (DBR) approach, the components and terminology that define it, the form in which it is applied in this study, and the rationale for its use. DBR uses a structure and terminology that differs from some more traditional research approaches. There is also a range of variations in the form that DBR may take. It is therefore important at this stage to clarify the basis of the approach used here, before examining the details presented in this study. This clarification and discussion may also contribute to theory relating to the use of a DBR approach.

Biglan (1973) suggested disciplines may be classified on the basis of how their content knowledge is framed, on a scale from hard to soft. STEM disciplines are classified within the hard-discipline category, described as strongly paradigmatic in that content knowledge is clearly defined, based on broadly accepted theories and with standard methods for advancing knowledge. Soft disciplines, which include the humanities and social sciences, and education, include a wider range of theories of knowledge, with a predominant view that knowledge is relative and is socially constructed, and represents "the standpoints and interests of dominant social groups" (Moore, 2013, p. 338). This study involves both hard and soft disciplines: it concerns implementing a technology within mathematically intensive (MI) disciplines, as hard disciplines, but using an educational research approach and methods that involve elements from soft disciplines. As Trowler (2014) notes, different disciplines have differing bodies of accepted theory, terminologies, and research strategies. There is the potential that some readers might be excluded by "the specialised language and other insider assumptions embedded in a discourse" (Weller, 2011, p. 95) - especially when the discourse crosses hard-soft discipline boundaries (Borrego, 2007; Wise & Quealy, 2006). The following sections define the terminology as it is applied in this research.

A *theoretical framework* is commonly determined to be an essential feature of academic research (Merriam & Tisdell, 2016). However, the precise nature of this term is not consistently defined and interpreted, and, at least in some interpretations, its nature and value has not gone uncontested (Eisenhart, 1991; Lester, 2005). Lesh and Sriraman (2005) describe a framework as "a system of thinking together with accompanying concepts, language, methodologies, tools, and so on" (p. 123). In this broad application of the term, a theoretical framework locates the research within a particular disciplinary genre and theoretical perspective. It, at least implicitly, may constrain not just the underlying accepted (or acceptable) theories and concepts but determine the standard methodologies and terminologies used in the research agenda, forms of its reporting, and avenues within which the research will be promulgated: according to Merriam and Tisdell (2016), "all aspects of a study are affected by the theoretical framework" (p. 89). However, it has been argued that strict adherence to a particular theoretical framework (of that form) can constrain the ambit of a research study and limit the practical uses of its outcomes (Eisenhart, 1991; Lester, 2005). Other uses of the term theoretical framework, in which it has a more limited scope, are discussed in following sections.

A *practical framework* has been suggested as one alternative to a theoretical framework, being built on practitioner experience and argued to offer more immediate practical benefits; however, as the approach is less concerned with theory building, the outcomes may have limited application outside the immediate context of the study (Eisenhart, 1991).

The term *conceptual framework* describes another alternative form of research framework. Although often used interchangeably with theoretical framework in research studies (Merriam & Tisdell, 2016), Eisenhart (1991) distinguishes a conceptual framework from both theoretical and practical frameworks, as “a skeletal structure of justification, rather than a skeletal structure of explanation based on formal logic … or accumulated experience” (p. 209). In any research study, “the framework may be based on different theories <u>and</u> various aspects of practitioner knowledge, depending on exactly what the researcher thinks (and can argue) will be relevant ...” (emphasis in the original) (p. 209). Eisenhart and Lester (2005) argue in favour of using a conceptual framework in research, as a better alternative to either a theoretical or practical framework, as it may draw on a wider range of sources, including different theories and practitioner knowledge, that can be justified as relevant to the particular research problem. As Lester (2005) elaborates, “a conceptual framework is an argument that the concepts chosen for investigation, and any anticipated relationships among them, will be appropriate and useful given the research problem under investigation” (p. 460). A conceptual framework in this form also validates the inclusion of practitioner knowledge, or “experiential knowledge", as it is termed by Maxwell (2013, p.44). This shared emphasis on both theoretical and practical concerns, adaptability to different research problems, and applicability to a pragmatic research approach, make the use of a conceptual framework particularly appropriate for this DBR study.

In distinguishing between theoretical and conceptual frameworks, it is also relevant to refer to the meaning of the terms *theory* and *concept*. While a range of different meanings may be implied in different contexts, the usage here may be related to standard dictionary definitions: of theory, as "a plausible or scientifically acceptable general principle or body of principles offered to explain phenomena" (theory, n.d.) and concept as "an abstract or generic idea generalized from particular instances" (concept, n.d.). In the context of this study a theory is taken to refer to an established system of ideas and is explanatory, whereas concept is taken to include ideas that may be less formally defined, and may allow broader scope when used in describing a proposition or conjecture for investigation.

Model is another term used in a range of overlapping ways. As used here, it refers to a simplified representation, often in a graphical form (and sometimes in equations), that may be used to explain (and explore) relationships, usually between a constrained set of phenomena. The term model may be used with a limited scope, to represent aspects of a singular theory, but also with a broader perspective, in which a model may "integrate ideas from a variety of theories" (Lesh & Sriraman, 2005, p. 502). Common models in the area of educational technology research include TPACK (Koehler, Shin, & Mishra, 2012), Substitution, Augmentation, Modification and Redefinition (SAMR) (Puentedura, 2010), and the Unified Theory of Acceptance and Use of Technology (UTAUT) (Venkatesh, Morris, Davis, & Davis, 2003); however, the varied and sometimes imprecise terminology of research in different fields can also see them described as theoretical frameworks, or just frameworks (as in the case of the preceding references).

DBR is a broad-based term, used to encompass a range of similarly named approaches, including design experiments, educational design research, and design research (Wang & Hannafin, 2005). DBR, and other variations, are not precisely, or uniquely defined in the literature, with varying interpretation by different authors, and across a range of disciplines (Anderson & Shattuck, 2012; Barab & Squire, 2004; Hartog, Beulens and Tramper, 2010; Herrington, 2012; Reeves, 2006; Wang & Hannafin, 2005). DBR is variously described as a "methodology" (Anderson & Shattuck, 2012; Wang & Hannafin, 2005) and "not in itself a methodology" (Herrington, 2012, p. 1), and "not so much *an* approach as it is a series of approaches" (Barab & Squire, 2004, p. 2). From a traditional social research perspective, Crotty (1998) defines a methodology as "the strategy, plan of action, process or design lying behind the choice and use of particular methods and linking the choice and use of methods to the desired outcome" (p. 3). As DBR is not prescriptive as to particular methods, or disciplinary perspective, the term *approach* is preferred here.

While there are wide variations in the details of implementing a DBR approach, there is a broad consensus on the general foundations of the approach. Sandoval (2014) notes that:

> Design research is defined mainly in terms of certain epistemic commitments that include, among others, the joint pursuit of practical improvement and theoretical refinement; cycles of design, enactment, analysis, and revision; and attempts to link processes of enactment to outcomes of interest (Sandoval, 2014, pp. 19–20).

Wang and Hannafin (2005) describe the approach as one “that emphasizes direct, scalable, and concurrent improvements in research, theory, and practice” (p. 6); Anderson and Shattuck (2012, p.16), stress a focus on meeting “the need for theory building and the development of design principles that guide, inform, and improve both practice and research in educational contexts.” (p. 16). In describing characteristics of design sciences in relation to mathematics education, Lesh and Sririman (2005) state:

> No Single ‘Grand Theory’ is likely to Provide Realistic Solutions to Realistically Complex Problems. … Therefore, in such situations, useful ways of thinking usually need to integrate concepts and conceptual systems drawn from more than a single practical or disciplinary perspective. Most will need to involve models which integrate ways of thinking drawn from a variety of theories and practices (p. 500).

While action research (AR) has developed as a largely separate genre from DBR (Kemmis, McTaggart, & Retallick, 2014), it shares some characteristics with DBR, having a common basis in pragmatism (Cole, Purao, Rossi, & Sein, 2005). There have been calls for more integration between AR and DBR approaches, building on the strengths of each (Cole et al., 2005; Iivari & Venable, 2009; Ørngreen, 2015). However, DBR is argued to differ in involving a wider range of participants, and not primarily just the practitioner as the researcher, and in having a broader emphasis on advancing a theoretical agenda along with meeting local practical needs (Anderson & Shattuck, 2012).

A criticism made of the DBR approach is that most writing about it has focussed on “what it is rather than how to do it” (Sandoval, 2014, p. 18). Sandoval has proposed a systematic approach called conjecture mapping, as “a means of specifying theoretically salient features of a learning environment design and mapping out how they are predicted to work together to produce desired outcomes” (p. 19). Figure 1 shows a generalised model of a conjecture map developed by Sandoval.

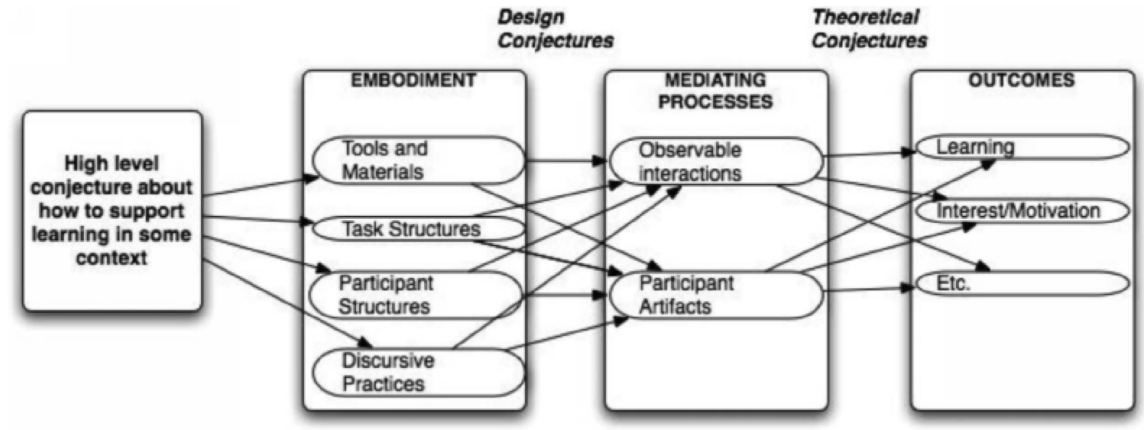

Figure 1. Generalised conjecture map for educational design research. From Sandoval, W. (2014). Conjecture Mapping: An Approach to Systematic Educational Design Research. *Journal of the Learning Sciences*, *23*(1), 18–36. doi:10.1080/10508406.2013.778204

A first stage in constructing a conjecture map involves identification of the high-level conjectures on which the intervention is justified; in this thesis, these conjectures may be equated to a conceptual framework, as a basis for action that draws on both theory and practical experience. In Sandoval’s model, these conjectures are then embodied in the learning environment design, as TOOLS AND MATERIALS, TASK STRUCTURES, PARTICIPANT STRUCTURES, and DISCURSIVE PRACTICES. These elements interact in implementing a design, with the effectiveness of the design manifest in identifiable *mediating processes*. The *outcomes* describe the means of evaluating the effect of these processes on learning, and link back to ultimately test the validity of conceptual framework on which the design is based.

Sandoval recognises that the proposed technique may have some limitations in its current form, particularly in how well it depicts developments and refinements over multiple cycles, and accounts for the influences of external factors. As will be discussed, the interventions studied here did not evolve in the context of a strategically managed technology intervention. However, the technique is nevertheless useful here to help document this research, by making explicit the conjectures underlying the interventions, the form in which these conjectures are expressed in a design, and in identifying processes by which both the effectiveness of the design implementation and the validity of the theories underpinning it might be justified.

In summary, for this study DBR is described as a pragmatic approach to research:

- that draws on a range of theories and practitioner knowledge that are made explicit in a conceptual framework;
- that uses this conceptual framework to formulate design conjectures that can guide the proposed form of development and enable evaluation of outcomes in both practical and theoretical terms;
- and which may be used to plan further cycles of improvement.

CHAPTER 3 / THE PEN-ENABLED TABLET PC PROJECT

Overview of the PenTPC Developments

This section discusses the overall developments in the introduction of penTPC technology in the university from the perspective of a DBR approach. These developments are described collectively as the penTPC project. The term project is used without capitalization to indicate the developments took the form of an initiative, or series of activities that shared a common purpose, but were not encompassed as a singular, planned, formal institutional Project. The basis for this project is summarised in the conjecture map in Figure 1.

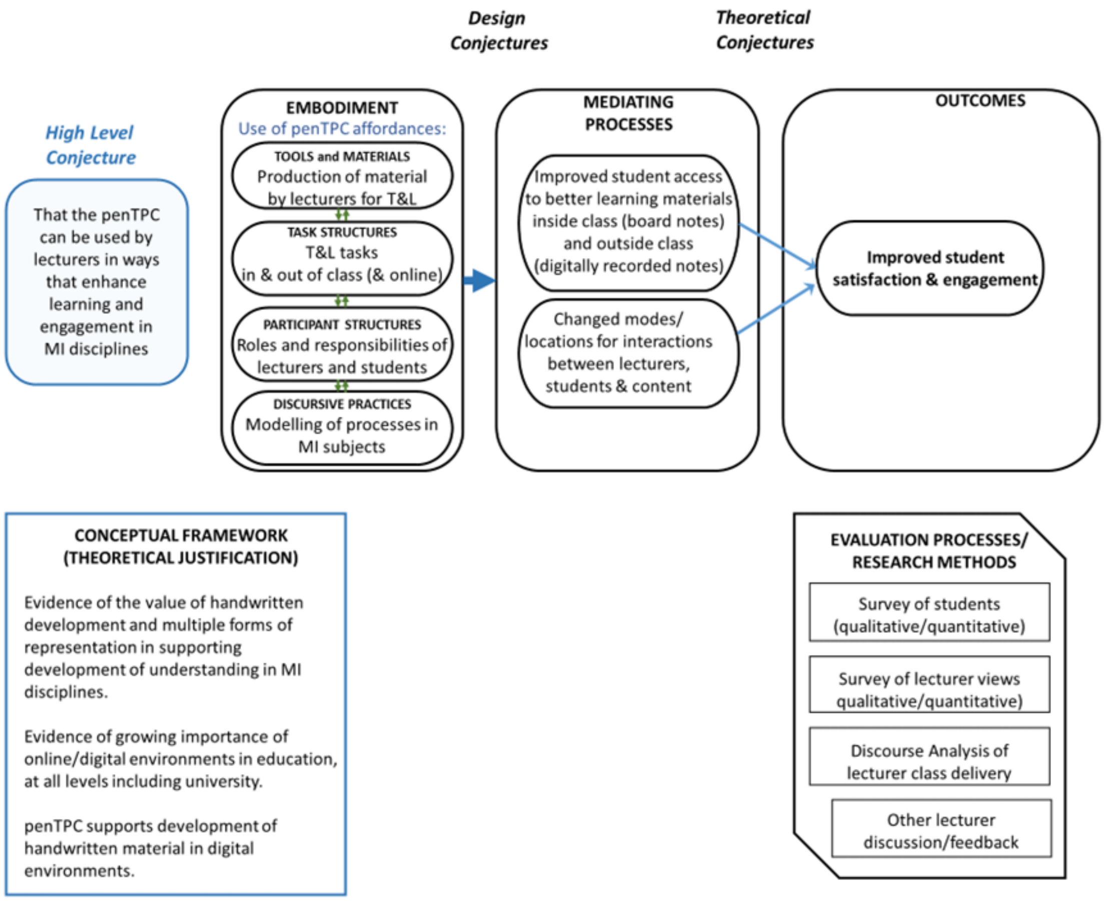

Figure 1. Conjecture map overview of penTPC project.

In terms of the overall penTPC project:

- There was a high-level conjecture that the penTPC could be used by lecturers in a tertiary environment for the teaching of MI subjects in ways that would enhance learning and engagement.

- This conjecture was supported by a conceptual framework, involving both theory and practical experience, that included:
    - Evidence of the value of handwritten development and multiple forms of representation in supporting development of understanding in MI disciplines;
    - Evidence of growing importance of online/digital environments in education, at all levels including university;
    - Evidence that the penTPC can support development of handwritten material in digital environments.
- The conjecture proposed that the affordances of the penTPC might be embodied in a design that:
    - uses the capabilities to deliver different forms of learning materials inside and outside class (TOOLS AND MATERIALS);
    - uses the capabilities to enable different tasks, or the performing of those tasks in new/different locations (TASK STRUCTURES);
    - uses the capabilities to enable lecturers and students to participate in different ways, with different roles and responsibilities (PARTICIPANT STRUCTURES);

    - uses the capabilities to enable digital interactions, and by restructuring task locations, also enables changes to in-class interactions (DISCURSIVE PRACTICES).
- The design might be manifest in mediating processes that provide improved delivery of learning materials and exposition of procedures, through use of digital artefacts both inside and outside class.
- Outcomes would be observable in improved student satisfaction and engagement (with improved student learning as an underlying goal).

Introduction of a new technology may often be based on an intuitive understanding of the underlying rationale and likely benefits; the conjecture map provides a lens that makes these explicit and reveals detailed aspects of the design. It relates those aspects explicitly to conceptual conjectures, and makes the details available for analysis and critique. The conjecture map in Figure 1 provides an overview that includes the possibility of a range of possible interactions. It therefore shows a single block-arrow linking embodied elements and mediating processes, rather than clouding the diagram with all possible linkages. It signals that the affordances of the penTPC have potential to have impact across a range of design aspects: changing the form of materials and the format may allow TASK STRUCTURES to be changed, potentially enabling different roles and responsibilities of participants, with changed DISCURSIVE PRACTICES, in different locations.

While not indicated in the conjecture map above, the project has also operated with an agenda that a perceived success of the technology might lead to lecturers being empowered to further explore the opportunities it provides for pedagogic inovation. It was also hoped that wider perceptions of success might lead to better institutional support.

In any educational study the measurement of outcomes is problematic. As Bereiter (2002) has noted, in educational settings the sheer number of variables that need to be accounted for, along with ethical considerations and other constraints, commonly render quantitative randomised controlled research approaches unfeasible. Furthermore, as Sandoval (2014) notes, DBR approaches such as this:

> often aim to innovate not just processes of instruction but the kinds of outcomes desired from instruction. Consequently, commonly available tests are inappropriate measures of ambitious outcomes. Second, it can be the case that the nature of desired outcomes is not very well conceived at the start of a design research project, and early cycles of design research maybe needed to clarify how those outcomes might be measured. (p. 14)

For example, performance as measured in formal examination papers has commonly been focussed on an assessment of procedural skills, rather than conceptual understanding (Gibson, 2002). Thus designs that seek to improve conceptual understanding may need changes in assessment processes, so that conceptual understanding is also measured.

In this study, qualitative and quantitative data was collected that explored the viewpoints of both students and lecturers. Participants in surveys were asked questions on a number of different aspects, with responses as ratings on a Likert-style scale. Examples included rating of: the effectiveness of use of a penTPC vs whiteboard vs PowerPoint for classroom presentation; the effectiveness of different forms of resources made available outside class. The resulting quantitative statistics were not used in isolation, but were triangulated with qualitative data (in the form of comments). This helped build a picture of how and why a design implementation might be seen to be working (or how and why a potential intervention might work). These were related back to the underlying conjectures and conceptual framework, to gain an understanding of whether changes did (or might in future) work as intended.

The approach taken in this study is thus a pragmatic DBR approach. This study reports on what is essentially a first iteration of intervention, with different aspects reported in the journal papers included as subsequent chapters. These initial findings are then examined, together with further theoretical evidence that relates to these findings, to suggest possible directions for further interventions. The intention of this study is encapsulated in the comment of Reeves (1999), as quoted by Herrington, McKenny, Reeves, and Oliver (2007):

> Research and evaluation efforts should be primarily developmental in nature … the purpose of such inquiry should be to improve, not to prove.
>
> (Reeves, 1999, p. 19)

The Conceptual Framework

Overview

This chapter outlines the initial conceptual framework for this study. It is not intended to function as a full literature review; each of the following Articles contains its own review of the literature pertinent to the particular Article, at the time the paper was prepared. Instead, this chapter provides a broad overview of the themes discussed throughout the papers. It elaborates on the theoretical and practical justifications for the use of the penTPC in teaching in MI disciplines, and the literature relating to previous work in this area. A review of additional literature related to aspects arising out of this initial DBR cycle, and of relevance to potential future cycles, is included within Chapter 10.

The context for this research lies at the intersection of several different knowledge domains, involving theories about discipline content knowledge, discipline-based pedagogical knowledge and the introduction and use of educational technologies. In the discipline domain, the subject areas of mathematics and its applications, including engineering, are distinctive in their use of symbolic and diagrammatic forms, and in theories of how knowledge is conceptualised. Although not the primary focus of this research, these theories about the nature of mathematical knowledge provide essential context. Theories of how to teach this knowledge effectively (or how to enable students to learn effectively) have also been developed in discipline specific forms, so that the theoretical foundations of mathematics education and engineering education are also relevant to this research. In addition, theories about why and how individuals and institutions adopt technologies are explored.

In this approach:

> rather than adhering to one particular theoretical perspective, we act as bricoleurs by adapting ideas from a range of theoretical sources to suit our goals—goals that should aim not only to deepen our fundamental understanding [of mathematics learning and teaching] but also to aid us in providing practical wisdom about problems practitioners care about.
>
> (Lester, 2005, p. 177)

Handwritten modes.

In mathematically intensive (MI) classes, handwritten modes with oral commentary have remained a common teaching form (Artemeva & Fox, 2011; Greiffenhagen, 2014). The basis for a handwritten approach lies in a discursive practice of expert modelling of theory and procedures. MI subjects require the development of complex reasoning, covering sequentially developed and dependent concepts within hierarchical knowledge structures. Greiffenhagen (2008) suggests “mathematical lectures are situations in which an experienced mathematician demonstrates mathematical expertise to novices as an important part of their progressive induction into professionally competent autonomous mathematical practice” (p. 11). Expert modelling was also identified by Bergsten (2007) as a key function of the mathematics lecture. Both the importance of demonstration and the complexity involved in the teaching of higher mathematics are evident in the statement of Vygotsky:

> If I know arithmetic, but run into difficulty with the solution of a complex problem, a demonstration will immediately lead to my own resolution of the problem. On the other hand, if I do not know higher mathematics, a demonstration of the resolution of a differential equation will not move my own thought in that direction by a single step. To imitate, there must be some possibility of moving from what I can do to what I cannot.
>
> (Vygotsky, 1987, p. 209)

As well as the use of handwriting, Schleppegrell (2007) suggested that "more than in any other discipline, the construction of knowledge about mathematics depends on the oral language explanations and interaction of the teacher" (p. 147), with the spoken language providing an essential link between symbolic and visual representations. This characteristic form of the mathematics lecture was described by Fox and Artemeva (2011) as 'chalk talk'.

While some have been critical of the ongoing use of teaching approaches that are seen as didactic and teacher centric, there have been strong arguments for continuation (in some form) of this ongoing use of demonstration, in a structured sequential progression, as a core component in MI teaching and learning. Furthermore, the use of a handwritten mode for the demonstration of procedures may serve multiple purposes: it inherently slows down the pace of delivery; the relative informality of handwritten material may make it more accessible; and the handwritten mode can readily allow integration of a range of representational forms and semiotic modes (discussed following). In regard to the use of the penTPC, a central DBR design issue becomes: how can the use of the technology enhance (and in some cases, restore) the use of this form of discursive practice?

Multiple representational forms

Within MI disciplines, the use of multiple representational forms, including hand drawn diagrams and equations, is essential to how knowledge is conveyed (Bunt, Terry, & Lank, 2009; Kober, 2015). The development of ways of thinking mathematically has been linked to the development of semiotic systems that may represent that knowledge, with new ways of thinking evolving with new forms of representation (Duval, 2006; Kaput, Noss, & Hoyles, 2002). For example, it was not until the sixteenth century that mathematics became really symbolic, and algebra developed as a field (Kaput et al., 2002; Mazur, 2014). Duval (1999) identifies the issues of being able to work both within and between different semiotic registers as being a source of problems for learners. He distinguished between two different types of transformations required to be used in mathematics. “Treatments” were defined as “transformations made within the same register of representation” (p. 8) (e.g. algebraic manipulation) and “conversions” as a translation into another register of representation (e.g. from an algebraic equation to a graphical representation). Handwritten approaches may provide the necessary flexibility to achieve fluency in the use of these transformations.

In a study of the use of pen and paper by mathematicians Misfeldt (2004) noted that the “graphical nature of mathematical notation makes pen and paper the preferred writing tool in many phases of mathematical work” (p. 1), particularly in the heuristic stages. This relevance of handwritten approaches in heuristic stages was also discussed by Bunt, Terry, and Lank (2009) who state:

> We found mathematicians make liberal use of sketches, mathematical expressions, and annotations to render abstract mathematical concepts more concrete. In the context of performing mathematical work, all of these representational forms can be viewed as dynamic objects that change over time, for example, as terms in an expression are crossed out, content is added to sketches, and new insights lead to new annotations (Bunt et al., 2009, p.2).

In engineering, the common range of representations used is extended to include the use of diagrammatic forms that range from illustrative diagrams to specialised technical diagrammatic representations. The value of diagrams in developing understanding has been explored by de Freitas and Sinclair, (2011) who suggest that diagrams “are more than depictions or pictures or metaphors, more than representations of existing knowledge; they are kinematic capturing devices, mechanisms for direct sampling that cut up space and allude to new dimensions and new structures" (p. 138).

Free-form sketching has been identified as an essential component of developing understanding in engineering (Bernold, 2013; Bilda & Demirkan, 2003; Grenier, 2008; Siew & Bernold, 2013; Yang & Cham, 2007). The diagrammatic representations used may facilitate the solution of problems by allowing the building of visual representations that can be converted to symbolic representations, allowing solving through appropriate "treatments" (i.e. the diagrams assist with formulating equations that can then be solved through algebraic or numeric methods). Even in situations of the interpretation of symbolic representations (e.g. equations) it has been suggested that spatial processing can be involved, and that handwritten forms may naturally embed a spatial encoding that may be missing from standard typewritten formats (Landy & Goldstone, 2007). In using a handwritten mode themselves, lecturers may model the processes in ways that students will themselves use in developing their own understandings.

Standard computer interfaces (i.e. mouse and keyboard) have limitations in supporting forms of mathematical thinking that involve dynamic development and transformation between symbolic and diagrammatic representations (Bunt et al., 2009; Misfeldt, 2004, 2011). However the use of computing technologies such as Computer Algebraic Systems (CAS) can allow the development of new kinds of representations that are not accessible in non-digital environments, and there is research that argues for an approach to mathematics and mathematics education that also incorporates these new representations, with the use of technology becoming infrastructural in thinking mathematically (Kaput, Hegedus, & Lesh, 2007). There are related arguments that the complexity of the traditional algebraic representational form that defines the “structure and core content of school and university curricula” has become an obstacle preventing many students from accessing the underlying ideas represented in mathematics (Kaput, Noss, & Hoyles, 2002, p. 58).

Gesture and annotation

While preceding sections have focussed on handwriting materials as a fundamental component in developing traditional mathematical thinking, other non-written and non-verbal components are involved in face-to-face communication. Radford (2008) determined “mathematical thinking does not occur solely in the head but also in and through a sophisticated semiotic coordination of speech, body, gestures, symbols and tools” (p. 111). Arzarello, Paola, Robutti and Sabena (2008) described the development of mathematical thinking as involving an interplay within a semiotic bundle incorporating speech, gestures and written representations (from sketches and diagrams to mathematical symbols). Goldin (2010) describes mathematical communication as taking place through “a vast array of complex and subtle external configurations” (p. 184) that cover:

> (1) spoken and written language; (2) iconic gesture, drawing, pictorial representation, musical and rhythmic productions; (3) mathematical formulas and equations; (4) expressions of goals, intent, planning, decision structures; (5) eye contact, facial expressions, body language, physical contact, tears and laughter, and exclamations that convey emotion (Goldin, 2010, p. 184).

Gesture and writing are naturally related, with Vygotsky (1978) describing gesture as “writing in the air”, and the written sign as frequently “simply gestures that have been fixed" (p 107). In the pen-enabled digital environment, some gestures may be restricted, as the use of the penTPC may limit mobility. Furthermore, since the visual display of the information created (on a projection screen) is separate from the location of its creation, traditional deictic hand gestures towards items on the creation-screen are not effective for the audience. However, these gestures might become transformed into a range of types of written annotation that perform a similar function in directing attention.

In studies on the use of 'digital ink', Anderson, Hoyer, Wolfman and Anderson (2004) described digital annotation in the penTPC environment as analogous to gesture. Lecturers working with penTPCs used attentional marks in the same way as a board user might use gesture; synchronously and co-expressively with speech.

De Freitas and Sinclair (2011) suggest a closer examination of the relationship between gesture and diagrams, drawing on the work of Châtelet (2000). Other studies have commented on factors such as the value of dynamic annotation (Ambikairajah, Epps, Sheng, & Celler, 2007) and the benefits of the use of colour (Fister & McCarthy, 2008). Choate, Kotsanas and Dawson's (2014) report on lecturers' experiences with the use of penTPCs also commented on the need for planning strategies in order to make best use of digital inking, and noted how lecturers had made significant gains in fluency of use three years after initial introduction of the technology.

Language and Imagery

Additional theory of relevance is Paivio's Dual Coding Theory (Paivio, 1991; Clark and Paivio 1991). Paivio (2006) identifies two systems involved in cognition: "a verbal system specialized for dealing directly with language" (p. 3) with representational units called logogens, and "a nonverbal (imagery) system specialized for dealing with nonlinguistic objects and events" (p. 3) with representational units called imagens. Along with cognitive load theory (Chandler & Sweller, 1991), this has implications for the way in which speech, symbols and imagery (i.e. diagrams and annotation) are combined and sequenced in the presentation of material. This supports the importance of oral commentary as a component of mathematical exposition, noted earlier. Goldin (2010) extends dual coding into a system with five representations, with addition of the formal notation of mathematics as a separate system along with a system of planning, monitoring and executive control and an affective system.

Affordances of penTPC

The term affordance as introduced by Gibson (1986) refers to "properties (of an object) taken with reference to the observer" (p. 137) that enable particular actions. The concept was refined by Norman (1999) to one of perceived affordances; it is what the user *perceives* the technology to be capable of that is relevant. As discussed following, the perceived affordances of a technology are a critical element in influencing its adoption. While the distinguishing affordance of the penTPC (compared to a laptop) is the capability to support handwritten input, it *also* incorporates the affordances of a laptop PC. This extends the potential use of the device to include online communication and collaboration, presentation and recording. The perceived affordances of the penTPC in relation to users' current and developing pedagogical approaches are a factor for consideration in researching their adoption of this technology.

While this research has focused on the use of penTPCs as a means of enabling writing in a digital environment, there will also be potential benefits in the affordances of the penTPC, through their computing capabilities, providing access to additional representations. While there has been widespread adoption of digital technologies for many applications of mathematics and engineering, with an extensive impact on curriculum and practice, there has been a continued expectation of the use of handwritten algebraic techniques and sketching in the development of solutions to basic mathematical and engineering applications. The ability to switch between a digital calculation/presentation mode in application software (such as MATLAB, CAD, R) and a handwritten mode (using software such as OneNote) while staying in the same technological environment may be of benefit in developing understanding of conversions between representations in different registers. For example, graphical output from calculation software can be inserted into a page and hand-annotated directly. The value of continuing to be able to use handwritten approaches when using software is reinforced by Kieran and Drijvers (2006) who suggest that the "epistemic value of paper-and-pencil techniques would seem to play a complementary, but essential, role" (p. 258) when students make use of Computer Algebra Systems.

Kaput, Hegedus and Lesh (2007) classified the affordances that are provided by computers into two main forms – computational and communications. An affordance of the penTPC environment is the capability to support collaboration using handwritten representations rather than just computational representations. However, the current environment for this research in this university is one in which the lecturer is the only participant that has guaranteed access to a penTPC, so collaborative interactions in handwritten environments are not an immediate focus of this research.

Digital devices and environments have become a central component in many aspects of life, including education. However, standard computing devices, reliant on keyboard and mouse input, do not facilitate hand written communications. While computers have obvious affordances in calculation and graphical display of digitally coded data, computers have tended to be used less in mathematics than other disciplines. Oviatt (2013) has identified the nature of the pen-based interface of the penTPC having the potential to bring the advantages of hand-drawn material to digital environment. From a DBR perspective, the tool has potential to enable discursive 'chalk talk' practices to be continued in the classroom, using digital presentation technologies (the data show), but also to enable different forms of materials to be created and shared in online digital environments.

Live lectures, Notetaking, Screencasts and Video Recordings

The capability to show dynamic development of mathematical arguments and modelling of expert thinking processes is a critical feature of the chalk talk teaching approach. A static digital recording of notes from a session is readily available when a penTPC is used. However, static notes do not capture critical elements from such lectures, requiring students to attend at the time and place of the lecture - unless dynamic recordings are made available for later viewing. Video recordings of live lectures, using 'lecture capture' tools are commonly made at many universities with some such as MIT providing open access to large numbers of recordings ("MIT OpenCourseWare | Free Online Course Materials," n.d.).

An alternative form of recording to the live lecture video is a screencast. These record the dynamic content on the computer screen (as displayed by a data projector if one is connected), and potentially any accompanying audio commentary, but without recording video of the person. If the computer in use has a digitiser, either integrated in the screen as in a penTPC, or attached as an accessory, then the screencast can record both handwriting and audio. As Yoon and Sneddon (2011) noted, penTPC generated screencasts allow the capture of a wide range of the lecturer's semiotic representations (with the important exception of gesture).

The effectiveness of the penTPC in producing screencasts has been widely reported (Bonnington, Oates, Parnell, Paterson, & Stratton, 2007; Cyr, 2013; de Grazia, Falconer, Nicodemus, & Medlin, 2012; Dean, 2006; Jordan, Loch, Lowe, Mestel, & Wilkins, 2012; Loch, Jordan, Lowe, & Mestel, 2014; O'Malley, 2012; Palaigeorgiou & Despotakis, 2010; Parker, 2011; Pinder-Grover, Millunchick, Bierwert, & Shuller, 2009; Yoon, Oates, & Sneddon, 2014). The relative ease of making recordings and making them readily available online has a potential impact on pedagogical approaches, by removing the limitations of time and space of the live lecture: the student no longer *has* to be present in class at a particular time.

A number of studies have examined the screencast in the context of a conventional tertiary pedagogical approach with screencasts used in a supplementary role to the physical lectures. In researching the effect on lecture attendance, Yoon and Sneddon (2011) found while a majority of students both attended lectures and watched recordings, for those students who relied on the screencasts as a replacement for lecture attendance, there was no measureable effect on final grades. There was a relationship with grades for those who skipped lectures *intending* to watch a recording, but did not. In this and a subsequent study it was proposed that the physical lecture needed to have strong elements of interactivity if attendance was to be valued over online recording (Yoon et al., 2014; Yoon

& Sneddon, 2011). The importance of lectures being active learning sessions in maintain attendance has been noted elsewhere (Billings-Gagliardi & Mazor, 2007).

While the focus of many studies has been in the recording of screencasts during the live lecture for use as a review resource, there is also potential for the screencast to be produced in advance and used as a preview study resource or for revision of prerequisite material. The production of short (typically less than 10min) topic oriented screencasts has become common in many educational settings. The Khan Academy (http://www.khanacademy.org) provides free access to an extensive range of screencasts covering a large range of mathematics and other STEM disciplines, and has been widely promoted (Thompson, 2011). The availability of screencast material for mathematical disciplines can allow the live class sessions to concentrate on discursive rather than transmissive activity. This approach has recently been associated with the notion of the flipped classroom.

Flipped or Inverted Classroom – the potential for pedagogic change

This research is not dependent on particular pedagogic approaches being adopted. The potential benefits of the penTPC in mathematical disciplines are not specific to a formal ‘lecture’ mode but apply to any context where the display of handwritten components can be of critical importance. While the research examined practices for effective introduction of this digital technology within the current learning and teaching environment and in support of current pedagogical approaches, this research also sought to examine how the technology might support development of new approaches in learning and teaching strategies.

The flipped or inverted classroom is a model of blended learning that is currently receiving widespread attention, with Margulieux, Bujak, McCracken and Majerich (2014) noting that “there were 10 papers on flipped/inverted classes at the American Society of Engineering Education conference in 2013 alone” (p. 10). The common elements of this approach typically involves content delivery focussed outside the classroom, followed by in-class collaborative activities that address more challenging conceptual issues (Bishop & Verleger, 2013; Houston & Lin, 2012; S. Khan, 2012; Tucker, 2012). Crouch and Mazur (2001) have developed an approach using what they term Peer Instruction (PI) in which students, rather than the lecturer, are involved in explaining concepts to their fellow students who then work through problems together.

In a flipped model, the screencast can play a vital role by providing the essential resources in the dynamic form needed in the study of mathematical disciplines. While it may be argued that the flipped classroom model may often still be enacted as a conservative teacher centric model, it can also develop in a collaborative student centric and constructivist approach.

Technology Adoption

Two broad (and intersecting) areas of research on technology adoption are of relevance. One area, following on from the work of Rogers (1983), relates to generic models examining influences on the adoption of technologies in a range of contexts. The second area looks specifically at educational technologies with a particular focus on the interactions between technology, pedagogy and content knowledge in discipline-specific contexts. In considering generic models of technology adoption, Venkatesh, Morris, Davis, and Davis (2003) examined the consolidation of eight alternative models into a

Unified Theory of Acceptance and Use of Technology (UTAUT), which they validated in a study of technology adoption in a non-academic environment. Anderson, Schwager and Kerns (2006) adapted this model in a study of the adoption of penTPCs in an academic College of Business setting, determining performance expectancy ("the degree to which an individual believes that using the system will help him or her increase job performance" (p.430)) to be the strongest predictor of technology acceptance. Venkatesh and Bala (2008), in a study in a commercial context, elaborated on earlier Technology Acceptance Models (TAM), researching the determinants of, and relationships between, perceived usefulness and perceived ease of use and the acceptance of a technology. They noted the importance to successful adoption of a design approach with user involvement in the implementation of interventions.

Annan (2008) examined technology adoption in the context of higher education and noted that faculty "must be convinced of the relevance of the technology to what they do in the classroom if they are to be convinced to change their current practices" (Annan, 2008, p. 16). Four additional factors of importance were also recorded: technology infrastructure that is "available, pervasive, nonintrusive, easy to use, and reliable" (p. 14); administrative support; pedagogical issues that may arise when the technology is adopted and used for teaching; and competing demands on faculty members (Annan, 2008).

While the perceived affordances of a device may encourage initial adoption of a technology, attention also needs to be given to the barriers that may prevent the successful use in practice. In a study of barriers to technology integration, Schoepp (2005) identified a need for planned, structured support in the integration of the technology. The importance of "effective support on key technology problems" was also identified by

Elzarka (2012, p. 97). Abrahams (2010) proposed a framework for identifying and prioritising issues and addressing barriers, in an approach that examined factors that *inhibit* faculty from using technology in instruction. Issues identified included the importance of providing troubleshooting support, appropriate infrastructure (i.e. “classroom ready” technology) and sufficient resources.

Although both Annan and Abrahams touch on the issue of the pedagogical relevance of technologies, the thrust of these and previously discussed models is on technology adoption in generic contexts. In the second group of models discussed below, the relationship of technology to their educational context is at the forefront.

Mishra and Koehler (2006) proposed the technology, pedagogy, and content knowledge (TPCK, later known as TPACK) model that emphasises “the connections, interactions, affordances, and constraints between and among content, pedagogy, and technology” (p. 1025). This model developed from the concept of pedagogical content knowledge (PCK) proposed by Shulman (1987), introducing technology as a third knowledge area (along with discipline content knowledge and pedagogical knowledge), but emphasising the critical importance of the intersection between pairs of areas (TCK, TPK, PCK) and between all three areas (TPCK, or TPACK).

Niess et al. (2009) examined the TPACK model in a mathematics education context, proposing a five-stage developmental process for how teachers may integrate a particular technology in their teaching, moving progressively from recognising, accepting, adapting, exploring, to advancing the purposes for which it might be applied. The TPACK model has been widely adopted as a model for conceptualising the issues of the introduction and use of technology in education, but with an ongoing debate on details of its interpretation and application (Voogt, Fisser, Pareja Roblin, Tondeur, & van Braak, 2013).

The realisation that technology was not just a tool for teaching existing knowledge, but could influence the nature of knowledge and how it is taught is not recent. Hooper and Reiber suggested in 1995 that "the curriculum and setting may also need to change to meet the opportunities that the technology may offer" (Hooper & Rieber, 1995, p. 1). Harris, Mishra and Koehler (2009) also commented on the potential impacts of technology:

> First, the advent of new technology has often changed fundamentally what we consider to be disciplinary content… Second, technology is not neutral with regard to its effects upon cognition… Finally, technological changes offer us new metaphors and languages for thinking about human cognition and our places in the world. (p. 400)

Institutional adoption of technology

While the choice to adopt a technology may in some instances be at the discretion of the individual, institutional factors may have a critical influence. New classrooms and theatres have been built to cater for larger numbers in generic disciplines and are often dominated by large projection screens and have limited whiteboard space. In many cases this change in architecture-technology has required a shift from the traditional chalk talk genre, to a genre based on predominantly static slides (i.e. PowerPoint). The effectiveness of such presentation technology has been widely criticised across all disciplines (Savoy, Proctor, & Salvendy, 2009). Within mathematical disciplines in particular, this presentation technology clearly limits the capability of the lecturer to dynamically demonstrate the reasoning processes underlying mathematical problem solving (the modelling of expert thinking), and the "pedagogically interactive, meaningful, and engaging" (Fox & Artemeva, 2011, p. 87) elements of chalk talk are diminished.

Lewin, Somekh and Steadman (2008) reported on stages in the introduction of the use of Interactive Whiteboards (IWB), with lecturers initially fitting the technology in with their established pedagogies, then collaboratively exploring new opportunities provided by these technologies, and later extending and transforming their pedagogic practices. This follows the progression inherent in the Substitution, Augmentation, Modification and Redefinition (SAMR) model proposed by Puentedura (2012), where stages in the introduction of new technologies are classified by levels of proposed use. It is suggested that the adoption of the penTPC technology may be facilitated where the initial introduction is at a Substitution (or Augmentation) level in relation to current practices i.e. where the perceived affordances of the device are seen to be relevant to the current teaching practices of the particular discipline.

Before considering the research design, it is appropriate to examine the organisational context for this research. Universities are complex organisations with a range of functional units, including academic faculty, executive management, estates management and information and communications technology (ICT) services. Salmon and Angood (2013) document research on the university organisation that identifies tensions arising from differences in approach by these different functional units, and between academic and ICT units in particular.

In considering research cycles, a critical issue is the difference in common planning and development cycle times between different functional units. For estates, planning cycles for development of new buildings may be in decades and of the order of several years for redevelopment of existing buildings. The development and upgrade of classroom technology such as audio visual systems (i.e. data projection equipment) will also be on a cycle of several years. ICT departments may also work on a planning frame of several years for introduction of new technology infrastructure, with computer hardware typically renewed on a three year cycle. An additional uncontrolled external factor is that of computer hardware and software (operating systems) development, which has seen increasing pace of change that has proven challenging for many institutional ICT departments.

For academic staff, programmes of study are generally reviewed on a 3-5 year cycle using a collaborative approach. While changes in curriculum and programme structure are commonly made in these reviews, it is less common to see substantive changes in pedagogical approaches, which can require significant resource allocation to implement (Singamnemi & Jowit, 2012). Particular papers may be reviewed on a semester or yearly basis, with decisions on delivery format and pedagogical approach commonly made by the individual instructor. Bates and others (Bates, 2001; Epper & Bates, 2001) have described current approaches of assigning the design and delivery of courses to individual instructors as a cottage industry approach, and called for development of theory and practice to inform team-based approaches that make best use of online and face-to-face environments (Bates, 2014).

An external factor which can influence the pedagogical approach of the individual lecturer is the design of the learning spaces and their embedded technologies (e.g. whiteboards, data-projectors). Where spaces and timetabling are managed centrally, lecturers may be timetabled to generic teaching spaces rather than have control over particular facilities in a customised teaching space.

The role of the researcher within this university is that of an academic *advisor* within a centrally based learning and teaching advisory unit, with no operational responsibilities or control. While this research is focussed on developing the effective use of the digital inking capabilities of penTPCs in teaching, there are a large number of factors identified above that may be outside the direct control of this research. However this context needs to be accommodated in the research approach.

Given the perceived potential for the penTPC to be used in a university context, in the teaching of MI disciplines in particular, this research aimed to examine the factors that influenced lecturers' adoption of this technology, the way in which they implemented the technology, and any adaptations they made in their pedagogical approaches.

Pen-enabled Tablet PCs (penTPCs) are being introduced at many universities, including this university. However, adoption of penTPC technology continues to be fragmented and unevenly supported. It has been widely commented that technologies should not be introduced just for their own sake but on the basis of an identified educational rationale; as Saloman (2016) wrote, "It's not just the tool but the educational rationale that counts" (p. 149). However, some digital technologies have become adopted, almost as a default practice, without there necessarily having being a detailed consideration of their educational rationale. Tools such as PowerPoint have infiltrated university teaching practices, even within mathematically intensive disciplines, which have traditionally relied on board-based presentation modes.

Experiential Knowledge

Maxwell (2013) argues that the researcher's technical knowledge and experience is an additional resource that is available to the study, and "both one of the most important conceptual resources and the one that is most seriously neglected in works on research design" (p.44). This experience may guide initial conceptions of both what to do and why, and provide useful insights that might otherwise be missed, and can be important in motivating and establishing the initial form of an innovation. By making the source of experiential knowledge explicit, it can be triangulated against the other theory and data gathered in a study, and potential sources of bias exposed.

In my case, my researcher experiential knowledge drew on:

- Undergraduate education in a traditional university engineering school, that involved use of conventional boards, and recalled experiences of trying to keep both recording and listening/understanding activities going at the same time.

- Ongoing experience of working with computing technology, from the days of mainframes, keyboard-based systems, punch cards and 24hr turnaround in programme runs.

- Training and teaching in primary education.

- Over 15 years' experience in teaching applied mathematics at a tertiary level, primarily tutorial style teaching in small classrooms using board-based technology – but with experience of technologies moving from chalk boards, to O.H.Ps, to whiteboards, and including PowerPoint.

- Completion of a master’s degree, studied online, in the field of online education and educational technology

- Over 5 years working in the development and support of learning management systems and in an advisory role on their use.

- 10 years’ experience working as an academic advisor, primarily within STEM disciplines.

When introduced to the Tablet PC, the opportunities to use it as an educational technology in support of STEM learning and teaching were immediately apparent.

Data Sources

This study is informed by the following specific instruments:

Preliminary Student Fast-feedback Survey

This survey is specifically referenced and analysed in Chapter 4 / Article 1. The form for this survey appears as Appendix 1.

This survey was conducted to give preliminary feedback on the use of handwritten presentation on penTPC projected through a data projector. Lecturers had reported students support (verbally and by show of hands) for the approach in classes in which the penTPC was introduced. This survey was intended quickly confirm the extent to which the intervention was regarded as having potential merit. The survey involved a single class being taught Engineering Mathematics in a lecture theatre seating approximately 100 students, with approximately 80 students present.

The survey asked students to compare the use of the penTPC with “other delivery approaches in similar situations”. While these alternative delivery methods were not specified in the survey wording, the introduction to the students made it clear that these methods covered handwritten whiteboard presentations and PowerPoint presentations that were being used previously. Students were also asked to provide brief comments on what they liked and disliked about the penTPC delivery method.

The survey was intended to give fast feedback on student views of penTPC use. It was not intended to provide substantive proof of particular hypothesises, but to provide guidance on the value of continuing with the use of the devices and to provide support for extending the pilot approach.

Student Survey – Lecture Presentation Methods and Online Resources

The survey form appears an Appendix 2. This survey is specifically referenced and analysed in:

Chapter 5 / Article 2 – Analysis of student preferences of delivery methods (Section A of survey)

Chapter 9 / Article 5– Analysis of student rating of resources used outside the classroom (Section C of survey)

Chapter 10 / Student and lecturer views on notetaking (Section B of survey)

Students from six distinct (in date, time and/or location) class sessions involving six lecturers teaching five different subjects within the university were surveyed in 2015. The selected sessions represented a convenience sample, based on timetabling and lecturer availability, from sessions in which the lecturer was using a penTPC in teaching MI engineering subjects. The sessions covered a range of levels, from first-year to third-year undergraduate level, with subjects including both general engineering mathematics and more specialised discipline areas such as mechanical engineering design and control engineering.

Table 1. 2015 Student survey details

Subject Area	Date	Lecturer	Respondents	Category
Engineering Mathematics	19/05/15	A	76	BEM
Engineering Mathematics	26/05/15	B	73	BEM
Engineering Mathematics II	28/05/15	C	96	BEM
BEM=Basic Engineering Mathematics			**Total 245**	**BEM**
Mechanical Design and Analysis	19/05/15	D	30	AAE
Advanced Mathematical Analysis	21/05/15	E	12	AAE
Advanced Engineering Numerical Methods	21/05/15	E	46	AAE
Mechanical Engineering Principles	19/08/15	F	147	AAE
AAE = Advanced and Applied Engineering			**Total 235**	**AAE**

The lecturers involved had varying levels of experience in the use of a penTPC, from those in their first semester of use to those with over three years of experience. Students were asked to give a response based on their general, overall experience of different aspects or delivery or resources, rather than their experience within the particular class that was surveyed. Responses were not analysed here in terms of class size, lecturer or class lecture environment. However the classes were categorised in terms of the nature of the subject, as being either Basic Engineering Mathematics (BEM) or Advanced and Applied Engineering (AAE); student in these two groups might be expected to have had a differing range of experiences based on their level of study.

Staff Survey – Tablet PCs and STEM Lecture Presentation Methods

The forms for this survey is listed in Appendix 2. The survey is specifically referenced and analysed in:

Chapter 6 / Article 3 – Analysis of student preferences of delivery methods

Chapter 9 / Article 5– Analysis of student rating of resources used outside the classroom

Chapter 10 Student and Lecturer Views on Notetaking

Responses were obtained from eleven lecturers, all of whom were using penTPC technology in teaching MI subjects, including all six lecturers involved in the student survey sessions (referenced above). The lecturers in the study were all experienced teachers within the disciplines of engineering and mathematics, but had varying levels of experience with the use of penTPCs. As discussed in Chapter 10, the intention was that the participant responses might be analysed as focus group comments, rather than treated as a rigorous representative sample.

Video Recordings of Lecturer Presentations

This data is specifically referenced and analysed in Chapter 6 / Article 3. As reported in that chapter, the study also involved analysis of video recordings of 7 lecturers using penTPCs in the classroom. In 5 of the sessions the recordings were made by the researcher, and in the other two sessions recordings were made by institutional support staff for the purpose of student access. The selection of the lecturers involved was essentially a convenience sample, drawn from the group who had participated in pilot projects involving use of a penTPC for teaching, who consented to be videoed, and where timetabling constraints allowed access to class sessions. The lecturers involved had varying levels of experience in use of a penTPC, from those in their first semester of use, to those with over three years of experience. The lecture sessions surveyed covered a range of subjects and levels within mathematics/engineering disciplines. One of the lecturers was no longer using a penTPC in the classroom, and had reverted to using a board. As reported in Chapter 6, while the number of lecturers involved was small, it was considered sufficient to give useful insights into current practices within the university (Nielsen, 2000; Tang & Davis, 1995).

Overview of the Articles arising from the PenTPC Developments

This section discusses individual articles that describe different aspects of the penTPC project from the perspective of a DBR approach.

Figure 2 shows the aspects explored in the different articles, and aspects of design that each addresses. As discussed in the Introduction, this project originally arose from work-related activities, rather than as a focus for this doctorate research, and proceeded in an institutional context that did not facilitate a carefully implemented DBR approach. However, aspects of a DBR approach were implicit in the early developments, and a DBR structure is used to describe and interpret the different aspects of the project.

Article 1/Chapter 4: THE NEW CHALKBOARD: THE ROLE OF DIGITAL PEN TECHNOLOGIES IN TERTIARY MATHEMATICS TEACHING.

- Overview of the rationale for the use of the penTPC as a lecture presentation tool in MI disciplines.
- Establishes a *conceptual framework* as basis for further development/investigation.

Article 2/Chapter 5: I SEE WHAT YOU ARE DOING: STUDENT VIEWS ON LECTURER USE OF TABLET PCS IN THE CLASSROOM - (FOR **PRESENTATION**).

- investigates student views on the use of the penTPC in a traditional lecture as a presentation tool
- in comparison to (replacement of) other modes (standard PowerPoint, whiteboard etc)

Focus on: in-class interactions, maintaining 'chalk talk' as a signature pedagogy

TOOLS and MATERIALS	Materials produced in class (board notes)
TASK STRUCTURES PARTICIPANT STRUCTURES DISCURSIVE PRACTICES	Lecturer as 'expert modeller'; student as notetaker

Article 3/Chapter 6: MAKING THE POINT: THE PLACE OF **GESTURE AND ANNOTATION** IN TEACHING STEM SUBJECTS USING PEN-ENABLED TABLET PCS.

- investigates usage of the penTPC by lecturer in classroom presentation of material.
- suggests annotation may be used as a (permanent written) substitute for gesture.

TOOLS and MATERIALS	Presentation of material
TASK STRUCTURES	
PARTICIPANT STRUCTURES	
DISCURSIVE PRACTICES	Lecturer use of gesture (& annotation)

Article 4/Chapter 8: INSTITUTIONAL ADOPTION OF AN INNOVATIVE LEARNING AND TEACHING TECHNOLOGY: THE CASE OF THE PEN-ENABLED TABLET PC.

- Examines institutional factors influencing the introduction of the penTPC in mathematically intensive disciplines.
- Suggests need to design alternative institutional practices for the introduction of innovation

Article 5 /Chapter 9: HOW IS THAT DONE? STUDENT VIEWS ON RESOURCES USED OUTSIDE THE ENGINEERING CLASSROOM.

- investigates student views on the resources they currently use outside the classroom.
- potential use of penTPC to develop alternative format materials for use outside class; change practices in class

TOOLS and MATERIALS	Potential for development of better, dynamic materials for use outside class (e.g. screencasts)
TASK STRUCTURES PARTICIPANT STRUCTURES DISCURSIVE PRACTICES	Enables change in tasks, structures and discursive practices within class (and outside class)

Chapter 10: STUDENT AND LECTURER VIEWS ON NOTETAKING (potential future article).

- investigates student and lecturer practices and attitudes in regard to notetaking and note provision.
- suggests annotation may be used as a (permanent written) substitute for gesture.

TOOLS and MATERIALS	Potential for alternative methods of provision of notes
TASK STRUCTURES PARTICIPANT STRUCTURES DISCURSIVE PRACTICES	Enables change in tasks, structures and discursive practices within class (and outside class)

Figure 2. Overview of Articles and their potential use of penTPC affordances.

Article 1

Maclaren, P. (2014). The new chalkboard: the role of digital pen technologies in tertiary mathematics teaching. *Teaching Mathematics and Its Applications: An International Journal of the IMA*. *33*(1), 16–26. doi:10.1093/teamat/hru001

This discusses the conceptual basis (covering theoretical and practical experiences) for the use of the penTPC as a replacement technology for the whiteboard in a lecture theatre or classroom. It draws on feedback from pilot investigations in the use of the penTPC that arose from the work-related development, and foreshadows issues for more substantive investigation in later papers.

Article 2

Maclaren, P., Wilson, D. I., & Klymchuk, S. (2017). I see what you are doing: Student views on lecturer use of Tablet PCs in the classroom. *Australasian Journal of Educational Technology, 33*(2), 173-188. doi:10.14742/ajet.3257

This paper describes a follow-up study of the introduction of the technology, examining how students responded to the use of the technology, with particular respect to the use as a presentation technology in classroom, compared to other options including whiteboards. This study involved a substantive mixed methods analysis of student views of a range of in-class presentation technologies. A survey was conducted of nearly 500 students and 11 staff. Students in the study indicated a strong preference for the use of the penTPC by lecturers. The study identified the maintenance of a handwritten approach, combined with ready visibility of material, support for inclusion of other digital outputs and post-class access to class material, were key factors influencing student preferences.

Article 3

Maclaren, P., Wilson, D. I., & Klymchuk, S. (2017). Making the point: the place of gesture and annotation in teaching STEM subjects using pen-enabled Tablet PCs. *Teaching Mathematics and Its Applications*. Published online 11 April 2017. doi:10.1093/teamat/hrx002

This paper examines use of the penTPC in the classroom from the perspective of the lecturer. It has been suggested that the use of the digital interface imposes restrictions on lecturer movement and gesture, compared to traditional board environments. This paper examined the adaptations made by lecturers in using the penTPC in a classroom environment, with particular attention to responses to the impact of moving from traditional whiteboards (and blackboards) to a small-screen interface, and the necessary strategies for responding changes in the availability of gesture and annotation as components in communicating in these different environments. The study suggests that the use of penTPC technology does not preclude the use of gesture, and that the augmented capability for annotation in conjunction with other digital representations can enhance teaching, particularly of STEM based discipline subjects.

Article 4

Maclaren, P. (2017). Institutional adoption of an innovative learning and teaching technology: The case of the pen-enabled Tablet PC. Manuscript under review at the *Australasian Journal of Educational Technology*.

Articles 1-3 in this thesis have examined the attitudes of lecturers and their students towards use of the penTPC from the perspective of those lecturers who have chosen to adopt them. These studies provide evidence of the potential of the devices to be used effectively in support of traditional approaches, where they are available. This paper investigates what proved to be a major issue affecting all aspects of this study: the negotiating of institutional access to the devices. As Rogers (1983) noted, in an institutional context “an individual cannot adopt a new idea until an organisation has previously adopted (it)” (p. 359). While this may appear obvious, the mechanisms by which institutional adoption of a technology occurs within a university may be complex. As in this case, adoption often occurs not in a planned way, but as an “emergent change” (Iles & Sutherland, 2001, p. 14), in which individuals seek to influence the direction of change and enlist resources (Cummings, Phillips, Tilbrook, & Lowe, 2005). While, as the previous papers suggest, there may be strong potential benefits of use of the technology, individual recognition of those benefits may not be sufficient; those wishing to see penTPC technology (or other learning technologies) made available may need to negotiate access in an approach that recognises potential institutional barriers This study suggests that initiatives for both individual and institutional adoption may need to be developed together in an iterative process.

Article 5

> Maclaren, P. (2017). How is that done? Student Views on Resources Used Outside the Engineering Classroom. *European Journal of Engineering Education.* Published online 5 November 2017. doi:10.1080/03043797.2017

Previous papers focussed on the use of the penTPC within the classroom in the traditional lecture context. In this Article the focus is changed to look at how the affordances of the penTPC might influence what students do outside class, with a particular interest in how the penTPC might be used to develop effective resources for use outside class. This study draws on the survey of students described in Article 2 above, and examines their views on the effectiveness of resources including textbooks, lecturer course notes, in-class developed notes, and other online material. Students indicated that lecturer generated material was generally seen as more effective than formal textbooks and social media. However, where material appropriate to their class was available, external screencasts were rated as most effective. This suggests that use of penTPC to develop appropriate screencast resources might facilitate improved learning outcomes, and with accompanying changes in assessment focus, may enable more substantive pedagogical changes.

CHAPTER 4 / ARTICLE 1 - THE NEW CHALKBOARD: THE ROLE OF DIGITAL PEN TECHNOLOGIES IN TERTIARY MATHEMATICS TEACHING

Published as:

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Submitted manuscript reformatted for this thesis.

Abstract

Traditional classroom teaching environments have used board technologies to incorporate handwritten elements within multimodal pedagogical approaches to developing mathematical thinking. In the tertiary sector increasing use of computing technologies based on keyboard and mouse interfaces and learning environments that emphasise digital displays constrain the use of handwritten elements. This article discusses how the use of pen-enabled Tablet PCs can provide support for handwritten elements, to build on the benefits of traditional pedagogical approaches and facilitate the development of new approaches.

Introduction and background

Within different disciplines, distinctive pedagogical approaches have evolved over time. Shulman (2005a) identified characteristic or signature pedagogies that are pervasive within particular professions and implicit in the way discipline knowledge is defined, developed, and valued. The dependence of mathematics on the use of symbolic and diagrammatic form for the expression and creation of knowledge has resulted in distinctive pedagogical approaches where hand-written elements have a key role within a broad multimodal approach (Artemeva & Fox, 2011). The combination of different elements in a multimodal approach is believed to be critical in the development of mathematical thinking.

Radford (2008) stated that “mathematical thinking does not occur solely in the head but also in and through a sophisticated semiotic coordination of speech, body, gestures, symbols and tools” (p. 111). Arzarello (2006) described the development of mathematical thinking as involving an interplay within a semiotic bundle incorporating “speech, gestures and written representations (from sketches and diagrams to mathematical symbols)” (p. 284). The use of handwritten elements allows the dynamic development of the written representations to be closely integrated with speech and gesture. In fact, gesture and writing are naturally related, with Vygotsky (1978) describing gestures as “writing in the air”, and written signs as frequently “simply gestures that have been fixed” (p. 107). The involvement of live handwriting means that the semiotic bundle includes the dynamic act of the writing of the signs, and not just the inclusion of previously formed signs.

In classroom and lecture theatre environments, the large board (chalk or white board) has traditionally provided the medium for live writing within a multimodal approach. Artemeva and Fox (2011) examined tertiary mathematics teaching across a range of countries and identified a common approach, “specific to the activity system of teaching undergraduate mathematics” (p. 370), in which board writing was accompanied by commentary and meta-commentary, and gesture. They termed this multimodal approach *chalk talk*.

The term *chalk and talk* is commonly used to describe a generic approach that has been criticised for being didactic and teacher centric. However, Fox and Artemeva (2011) maintained that chalk talk can be “pedagogically interactive, meaningful, and engaging” (p. 87) in the context of mathematics education. While looking closely at the dynamics of lecturer teaching approaches, their study also revealed agreement among lecturers on the essential need to be able to write while teaching mathematics, quoting one experienced lecturer as stating ‘I cannot do mathematics, for the most part, without writing’ (Artemeva & Fox, 2011, p. 367). In reviewing the linguistic challenges of mathematics teaching and learning, Schleppegrell (2007) suggested that “more than in any other discipline, the construction of knowledge about mathematics depends on the oral language explanations and interaction of the teacher” (p. 147), with the spoken language providing an essential link between symbolic and visual representations.

Even the proponents of alternative teaching approaches such as problem and project based learning recognised the value of these traditional didactic approaches, particularly in the early years of tertiary study in mathematics-based disciplines (Perrenet, Bouhuijs, & Smits, 2000; Mills & Treagust, 2003). As Samuelsson (2010) noted, different teaching approaches, including traditional and problem solving approaches, can develop different areas of mathematical proficiency, and it may be that an eclectic approach has advantages.

While the mathematics-specific method of multimodal handwritten and oral exposition has a particular manifestation as chalk talk in the context of the lecture, the essential components of the approach are also relevant in any context where mathematical thinking is dynamically shared. Even in the case of two individuals exploring a problem together, a handwritten component can be of critical importance.

If educational environments that are used in the teaching of mathematics are to support all the elements involved in developing mathematical thinking, they need to include technologies that support live writing. This article discusses how technological and organisational changes have impacted on the use of traditional handwriting elements in current tertiary learning and teaching environments, and describes how the use of pen enabled digital technologies have been used to restore support for these elements. While the focus of the article is on the use of this digital technology in the context of traditional environments and pedagogical approaches, the article also suggests how the technology might support development of new approaches and support a range of learning and teaching strategies.

Organisational influences on teaching technologies

Early teaching technologies were dependent on handwritten input, and were used in common across all disciplines. The chalkboard became a standard starting in the 1800s, with a range of newer technologies being introduced progressively: the whiteboard (or dry erase board) began to supplant chalkboards in the 1980s; the overhead projector began to supplement writing boards from around the 1950s (Krause, 2000; Kidwell, Ackerberg-Hastings, & Roberts, 2008). More recent technologies that have been promoted are the document camera (Brooks-Young, 2007) and, particularly in primary and secondary classrooms, the interactive whiteboard (Brown, 2003; Higgins, Beauchamp, & Miller, 2007).

Shulman (2005b) suggested that signature pedagogies both influence, and are influenced by, the design of the learning spaces in which they are practiced and the educational technologies that they use. Where tertiary teaching spaces are managed by departments structured on a discipline basis, spaces can be more readily customised to suit the particular discipline needs. University teachers of mathematics have frequently expressed strong preference for the use of writing boards in their principal instructional approach, and have retained boards in their own teaching spaces (Artemeva & Fox, 2011; Greiffenhagen, 2014).

However in many institutions responsibility for the management of rooms and associated educational technology has now been centralised. A goal of improving efficiency has encouraged standardisation of the technology provided in teaching spaces, with rooms allocated through a centralised timetabling system. Accompanying these organisational changes have often been institutional based initiatives for architectural, technical and pedagogical innovation (Jamieson, Fisher, Gilding, Taylor, & Trevitt, 2000; Neary & Saunders, 2011). Implicit in the development of new classroom environments has been the view that many current learning spaces and their technologies are "unsuited for the emerging pedagogy in higher education" (Jamieson, Miglis, Holm, & Peacock, 2007, p. 11).

Large board technologies (and blackboards in particular) have been regarded as an old-fashioned technology, associated with an outdated lecture theatre based "teacher-led, didactic practice" that should be replaced (Jamieson et al., 2007, p. 11). This has resulted in conflicts such as noted by Greiffenhagen (2014) who quotes mathematics faculty as stating that they had "for many years been battling with Estates and Services to retain blackboards in the teaching rooms that we use" (p. 19).

The institutional approach to standardise technologies in teaching rooms and encourage new forms of teaching and learning is not recent. A 1998 report from Heriot-Watt University (Marsland, Tomes, & McAndrew, 1998) describes a project for the refurbishment of a 100 seat lecture theatre, involving removing two existing roller chalkboards, retaining OHPs and a 35mm projector, and introducing a range of new digital technologies. The report records the mathematics department as registering concern at what they saw as reduced support for hand writing, resulting in a low-mounted whiteboard being added toward the end of the refurbishment. In response to ongoing expressions of dissatisfaction, the report suggested that an alternative to adapting to the capabilities of the available technology might be “to designate rooms to best support the different styles of teaching” (Marsland et al., 1998, p. 29), and adapting the timetabling system to include data on the technologies available in different rooms.

The issues of the interaction of new technology, learning spaces and pedagogical approach are on-going. At AUT, a new building has just been opened, which includes a number of innovative types of classroom-scale learning spaces, but also includes a large (385 seat) traditional lecture theatre, a smaller lecture theatre and a case-room. The technology setup of the theatres follows the trend towards emphasising digital technology, with multiple data projectors - but no whiteboards. The scale of these larger rooms is such that the limitations of a whiteboard on readability from a distance would make them an impractical option. Again, concerns were expressed by lecturers in mathematics based disciplines about the lack of writing capability; again, moving mathematics classes into different rooms where whiteboards were available was a suggested solution.

Whiteboards are present in some form in all smaller classrooms in the new building, but their dimensions are variable and their placement and lighting is often a secondary consideration to the requirements of a data projector. While a number of theatres spaces are equipped with a document camera, and two have digitiser monitors, these are not universally available in all teaching spaces. In fact, the only common display technology now across all teaching spaces at AUT is the digital data projector connected to a standard PC.

This article is not arguing against innovation in technology and pedagogy, or against development of innovative teaching spaces. However it is important, as Boys (2009) argues, to critically examine the appropriateness of all aspects of these innovations, and the underlying assumptions, for all contexts (and for all disciplines). It is also worth noting that while there are pedagogical arguments against the large class model, its use continues worldwide. Foreman (2003) suggests this is "mainly because it is cheap and pragmatically useful: the economies of scale generate a surplus that supports low teacher-student ratios in major classes" (p. 12). Thus large lecture theatres continue to be a feature on most university campuses, and continue to be built, even within new building developments that have been designed to foster innovative approaches, as at AUT.

It is also not intended here to argue the case for or against the use of the lecture in mathematics education; however it is argued that wherever mathematics is to be presented and discussed in a class environment, the environment should provide the capability to support a multimodal approach incorporating writing and oral modes. Artemeva and Fox (2011) recognised that the usefulness of chalk talk is not bound specifically to the use of the technology of the chalk (or white) board, and as they and Schleppegrell (2007) note, it is the ability to *combine* oral and writing modes that may be a critical element in developing mathematical thinking. The next section examines the influence of the introduction of digital technologies, and argues that while the use of digital technologies may be promoted as progressive, if dynamic handwritten methods are not supported, their use may be disadvantageous in mathematical contexts.

Limitations of standard digital interfaces in mathematics teaching and learning

As noted in the previous section, the data projector displaying material from a computer controlled through the keyboard/mouse interface has become the primary teaching technology in many tertiary teaching environments. In the absence of suitable whiteboards, or even document cameras, to support handwriting, lecturers in mathematical disciplines timetabled in large spaces have often abandoned chalk talk approaches and resorted to using the digital technology to display pre-prepared material (i.e. PowerPoint slides). In this case, a change (in availability) of technology forces (rather than motivates) a change in use of modalities, with a loss of dynamic handwriting capability. As discussed in the previous section, the loss of this modality may have a critical impact on the development of mathematical thinking.

Various studies have reviewed the effectiveness of PowerPoint, with mixed results, even without regard to specific needs of mathematical disciplines. (Craig & Amernic, 2006; Levasseur & Kanan Sawyer, 2006; Savoy, Proctor, & Salvendy, 2009; Berk, 2011). Mann & Robinson (2009) suggest that the use of PowerPoint is a major factor contributing to student boredom in the lecture theatre. Savoy et al. (2009) perhaps come closest to a consideration of the specific needs of mathematical disciplines with their recommendation that "if students are expected to retain information and/or concepts that are best conveyed through dialogue or verbal explanation, traditional presentations appear to be best" (p. 866).

The interlinking of commentary and gesture with dynamic development of equations and diagrams that is provided by chalk talk board technologies is not supported by the pre-prepared digital slide show. The timing of delivery is not constrained by the speed of writing, and slides can be clicked through at a pace unrelated to student response (or lack of response). The opportunity to deviate from pre-written material to clarify points is constrained. As Greiffenhagen (2014) noted, "it is important that a presenter has to write out the proof on the board (rather than simply display it on a slide and then point to it), since this makes visible the process of mathematical reasoning" (p. 20).

The loss of capabilities in moving from handwriting to a standard digital interface is an example of what McLuhan (1994) termed an amputation effect associated with the introduction of new technologies. If the capability to write freely when teaching the doing of mathematics is lost, the use of a technology may limit the capability to develop mathematical thinking. In interpreting and elaborating on McLuhan's analysis, Moore (2006) suggests that "the application of a new technology requires a trade-off and we are encouraged to exercise careful judgement to ensure the trade-off is a worthwhile one" (p.405).

It would appear that the reluctance of many mathematics lecturers to give up writing boards might be based on an assessment that the trade-off in adopting digital technology in place of a standard interface is not worthwhile. In an analysis that expands on McLuhan's ideas, Hancock, Parton, Oescher and Smolka (2012) suggest the use of an instrument for the evaluation of new technologies, that asks questions as to what a new technology facilitates, what it renders obsolete (or inaccessible), what are the associated costs, and what is its potential impact.

Different educational technology tools have different capabilities, and different limitations in particular learning environments. At the Auckland University of Technology (AUT), large monitors incorporating pen digitisers have now been installed in some lecture theatres. However a key issue for staff adoption of technology is whether they can rely on it to be available in all their timetabled teaching spaces (Spotts, 1999; Brill & Galloway, 2007). Rather than seek to provide standard devices that are room based, providing portable devices that are lecturer managed and can be readily taken *to* rooms may be a better alternative as a means of providing handwriting capability. The next section describes the use of pen-enabled tablet PC technology that has been introduced to provide such a capability.

Introduction of a New Technology - The Pen Enabled Tablet PC

While most computing technologies remain keyboard-mouse centric, the Tablet PC is a mature digital technology that supports precise hand-drawn pen input, with embedded digitisers able to provide the control required for detailed symbolic and diagrammatic mathematical writing. It should be noted that this pen technology uses a more precise technology that is available in devices that rely solely on capacitive touch, such as the iPad. Digitiser pen technology provides highly accurate positional resolution and a pressure-sensitive thickness response; the sensor technology detects the presence of the pen as it approaches the screen, so that the hand can be rested on the screen without producing unwanted inputs. This technology is able to provide a relatively natural writing experience that can be readily adopted by the new user without major difficulty. With integrated pen support provided by the Microsoft Windows Operating System and inking tools available in standard and specialised software, the Tablet PC has the capabilities to support fluent input of handwritten mathematics.

At AUT a pilot project to use Tablet PCs was initiated in 2012, involving lecturers from the School of Engineering, using five HP2760P pen-enabled Tablet PCs in lecture and classroom sessions (Maclaren, Singamnemi, & Wilson, 2013). Despite implementation delays allowing for limited training in the use of the device, staff were able to quickly adopt the technology. While there were some initial technical teething problems, staff were encouraged to work through those issues by the overwhelmingly positive response of the students; in one class fast-feedback survey, 74 of 77 students (96%) rated the presentation approach as superior to other methods that had been used with them. One lecturer, who was teaching a primarily non-mathematical subject, found the Tablet PC did not particularly suit his teaching approach, and this Tablet was passed on to another lecturer involved in teaching a mathematics intensive course.

The importance to both lecturers and students of mathematical processes being dynamically modelled using handwritten modes is apparent from corresponding comments from the AUT pilot study and the Artemeva and Fox (2011) study involving board-writing (Table 1). The value of the handwritten approach in pacing lessons and enabling adaptability and spontaneity was acknowledged by both lecturers (using boards) in the international study and by AUT students in the Tablet PC environment. It is clear that the Tablet PC has provided suitable access to the essential modality of handwriting and narration that is a key component of the chalk talk approach. As Artemeva and Fox had recognised "it is important to stress that this consistent view of the usefulness of chalk talk in no way precludes the introduction of advanced technology to university mathematics classes" (p. 358).

Student Comments (AUT 2012)	Lecturer Comments [from Artemeva & Fox (2011)]
This method is more effective in a way since we get to see all the steps required/executed in order to attain the final answer	. . . you need to show . . . what you're thinking; you need to show the process in order to teach that
The lecturer goes much slower in the lecture and covers the material one step at a time rather than displaying a PowerPoint slide with lots of words which can be hard to follow.	... with overheads and a computer [Ppt] presentation you can go way faster than the students or anybody can comprehend the mathematical stuff.
It shows the step by step explanation before the materials reach the important part	without visual aid, and the time line that comes from writing it all down, . . . it's impossible to appreciate [the logical constructions]
Slows down lecture so notes can be taken. Because it is handwritten it's easier to copy down.	. . . the writing, the act of writing, keeps the pace

Table 1. Comparison of Student Comments from a 2012 AUT Pilot Study Student with Lecturer Comments from Artemeva and Fox (2011)

In the AUT pilot study, students also commented on functional improvements of the projected handwritten material over handwritten whiteboard material in the lecture theatre: the screen was much easier to see and read from anywhere in the room; the lecturer did not block the view; material was scrollable and correctable, and was not constantly being rubbed out; different colours could be used to highlight different aspects; pens didn't run out and writing was larger and clearer; notes were recorded and could be made available later. Particularly in larger rooms, this use of digital technology can enhance the student experience while maintaining a handwriting capability.

A critical issue for effective use of the Tablet PC is room furniture allowing for suitable physical placement of the tablet. The lecturer needs to be able to write easily, but also engage with the class. In an account of staff experiences in trialling tablets, King, Robinson, Davis, and Ward (2008) record an issue one lecturer has with having to "stoop to write". With the introduction of any new technology, the functional details relating to practical use within the rooms need to be established in consultation with the users. Marsland et al. (1998) describe reactions to the installation of whiteboards in the Heriot-Watt University:

> The boards are a disaster. You almost have to lie on the floor to write on them. The screens are the wrong height so that the first four rows of students can't see.
>
> The board needs to be lighted. Whenever I taught at the board I felt that I was writing in the dark! The promised supply of pens quickly ran out and was not replenished regularly. There is no place to put down the marking pens when one pauses while writing on the board. (p. 23)

Just as boards need to be positioned on the wall at the right height, appropriate support for Tablet PCs needs to be provided. While most lecturers in the AUT trial stood at lecterns, one lecturer used a strategy of sitting at the side of the datashow. The ability to use wireless display capabilities to connect to the datashow, to allow more freedom of movement is also being investigated.

The reliability of *any* new technology is a critical factor affecting adoption. In a web posting discussing the merits of the use of the document camera, one respondent notes:

Finally, one advantage of using the chalkboard is that it never malfunctions! …. With any other technology you have to think about whether you want to spend your time playing around with technology. This is especially frustrating, I think, if scheduling forces you to spend time getting things hooked up *after the time your class is supposed to start* (say, if you teach in a room where the person before you usually overruns). Your students don't want to watch you trying to get the camera working. (AskMetaFilter.com).

As with any new technology, initial use is often by the enthusiastic early adopters (Rogers, 1983) who are willing and able to work through technical issues that may become a barrier for the later adopter. As King, Robinson, Davis and Ward (2008) note, technical issues tend to diminish with time as staff confidence and expertise grows, and as solutions to technical issues are resolved. In the case of the AUT experience, the enthusiasm of the students for the new approach, and their acceptance of the teething problems, helped encourage staff to persist with the approach. The issue of dependability is not just an issue of reliability of the Tablet PC itself, but extends to the interaction with data projectors and wiring systems. Differing data projector specifications and different wiring configurations have continued to present issues, particularly with changing standards in the output technologies in new Tablet PCs (i.e. no native VGA output).

For the lecturers, the change from the use of large board technologies to writing on a small screen is not seamless, and requires adaptation which will take time to refine. There are also changes in the writing action, from large motor actions in board writing to small motor actions in handwriting. Just as development of large board writing skills may take new lecturers time to develop, the refinement of handwriting may require a readjustment and redevelopment to ensure legibility when projected.

Artemeva and Fox (2011) identified a common systematised approach to the use of large writing boards that they described as "board choreography" (p. 359). While large board choreography has evolved over many years and become a signature of mathematics teaching, tablet digitiser choreography on the small screen requires different strategies. Where multiple large boards are available, previous written steps remain viewable. On the small screen, the previous steps are not erased, but may not be immediately visible in any one view. The layout on the screen is open to a range of approaches, from treating the screen as a series of discrete pages, or slides, or as a continuous virtual scroll of paper. While the use of gesture flows easily when using a large board, gestures are constrained when in the pen-on-screen environment.

However, there are also immediately obvious advantages in the use of these tablet modes. The use of colour is more accessible, and direct pen annotation is enabled. Images and diagrams from other sources can be incorporated in the presentation, along with output from mathematical software packages. The Tablet PC provides not just the handwriting capabilities for chalk talk, but also supports a full range of PC computer applications. The lecturer is able to switch instantly between a handwritten problem, mathematical software, video material, or to online course material and references, without requiring a change in lighting and room setup.

Lecturers are continuing to explore the use of different software to provide the virtual board, different approaches to page layout and problem development, and variations on the physical positioning of the device. While there is an established model for a fluent chalk talk approach with large boards, best methods for utilising the small Tablet PC screen will continue to evolve.

The project is entering a second phase where other lecturers are taking up the technology on the recommendation of the pilot users and evidence of the enthusiasm of students. For many lecturers, faced with new teaching spaces where whiteboards are unavailable or would be unreadable, the digitiser technology embedded in the Tablet PC appears to be the best technology option to support their current preferred pedagogical approach. The next section examines how the Tablet PC might go beyond supporting existing pedagogies, and facilitate development of new approaches.

Developing New Approaches

Shulman (2005a) suggests possible contradictory reasons why signature pedagogies survive: they may be perpetuated because they succeed (a Darwinian perspective), but also because of inertia, in that nothing deflects them (a Newtonian perspective). In Darwinian terms, it is arguable that signature pedagogies are perpetuated because those that become teachers and use them are likely to be those that best succeeded in learning with them. This would imply a need to examine approaches that might work better for those students who are not succeeding with them. Shulman (2005b) also suggested that new technologies, particularly online digital technologies, "create an opportunity for re-examining the fundamental signatures we have so long taken for granted" (p. 59).

The initial introduction of Tablet PC technology has been, in the terminology of Puentedura's (2012) SAMR model, in a substitution or augmentation role. Tablet PCs have taken the place of the whiteboards, while maintaining existing pedagogical approaches (or replaced the use of PowerPoint). Krause (2000) suggests that historically, success in the effective introduction of technologies such as the chalkboard has come where the new technologies have been seen to enhance existing accepted pedagogical approaches. He argues that for successful change which involves both a new pedagogy and a new technology, the driver for the change must be the pedagogy, with the new technology the facilitator, rather than the reverse.

The Tablet PC is a technology that supports existing traditional approaches by facilitating continuing use of multimodal oral and written approaches in class environments, but it can also facilitate pedagogical change. It can enhance engagement and collaboration in the less (space and time) constrained online environments, by enabling multimodal capabilities not provided by traditional digital interfaces.

While the experienced lecturer can adapt pacing in the classroom to suit perceived overall needs of the class, it is not possible to fully cater for individual differences. Golub (2004) quotes instances of students coming to ask questions related to course notes where they think they may have written them incorrectly, or know they didn't copy down what was written "because they were paying attention to the discussion and did not want to divide that attention" (pp. 53-54).

Recordings of lessons, incorporating audio and writing, can be made available to students, allowing them to pause, reflect and replay as they require. Such recordings, of audio and writing on the screen, can be readily made on the Tablet PC without needing external video cameras. Commonly referred to as screencasts, they can provide access to the multimodal benefits of chalk talk, but in a format that can be accessed asynchronously from a resource repository (Loch, Gill and Croft, 2012). This type of recording has achieved popular success in the public offerings of the Khan Academy (Thompson, 2011).

Screencasts can also be a key element of more transformational approaches. The flipped or inverted classroom is a model that is currently receiving widespread attention. It was noted that "there were 10 papers on flipped/inverted classes at the American Society of Engineering Education conference in 2013 alone" (Margulieu, Bujak, McCracken and Majerich, 2014, p. 8). Common elements of new approaches typically involve content delivery focussed outside the classroom, using resources such as screencasts where the student can adjust the pace, followed by in-class collaborative activities that address more challenging conceptual issues (Khan, 2012; Tucker, 2012; Houston & Lin, 2012). Crouch and Mazur (2001) have developed an approach using what they term Peer Instruction (PI) in which students, rather than the lecturer, are involved in explaining concepts to their fellow students and work through problems together.

While the use of Tablet PCs by lecturers has been the initial focus of use at AUT, the devices have the potential to deliver benefits when available to students. Romney (2010) notes the difficulty for students in trying to take live notes in mathematics classes using keyboard and mouse interfaces. Studies by Anthony, Yang, and Koedinger (2006) show that on computer devices that allow handwritten input, extraneous cognitive load is reduced when using handwriting over keyboard input, and that hand written and hand drawn input provides "better support for the two-dimensional spatial components of mathematics" (p. 2077).

The use of Tablet PCs can allow the student to integrate their handwritten material directly into their computer based online environment, enabling a wide range of student centric and collaborative pedagogical approaches (Loch, Galligan, Hobohm, & McDonald, 2011; Romney, 2011). Radosevich and Kahn (2006) found that student use of Tablet PCs enabled a change in pedagogical approach that promoted "a dynamic, student-centered learning atmosphere" (p. 5) with positive effects on learning. The use of Tablet PCs with screen sharing software extends collaborative capabilities to include the use of hand-written and hand-drawn input by physically separated groups of students and staff working synchronously in problem and project based approaches.

The successful experience with lecturer adoption of Tablet PCs is not unique to AUT, and has been reported elsewhere (Galligan, Loch, McDonald, & Taylor, 2010). These experiences suggest that Tablet PC technology can gain acceptance from faculty teaching in mathematics based disciplines because it can provide access to the familiar handwritten pedagogical approach of chalk talk within an institutional digital environment. The capabilities of the technology provide opportunities for further development of pedagogies involving contexts outside the classroom. The opportunities to further develop pedagogical approaches will expand as students gain personal access to the technology. While it is common to have positive reports from early adopters of technologies, and it is difficult to predict long term impacts with rapidly changing technologies, the pen-enabled digital tablet looks to have the potential to make a significant contribution as a tool in mathematics education.

References

See References section at end of Thesis.

CHAPTER 5 / ARTICLE 2 - I SEE WHAT YOU ARE DOING: STUDENT VIEWS ON LECTURER USE OF TABLET PCS IN THE ENGINEERING MATHEMATICS CLASSROOM

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Abstract

Mathematically intensive engineering subjects at a tertiary level have traditionally been taught in classroom environments using whiteboards or blackboards. This paper reports on student views of the effectiveness of board and alternative technologies used within existing classroom contexts. Students in this study revealed a strong preference for the use of pen-enabled tablet PCs as a delivery technology. The maintenance of a handwritten approach, combined with ready visibility of material, support for inclusion of other digital outputs and post-class access to material, were key factors influencing student preferences. Although this introduction of technology did not involve substantive changes in classroom pedagogical approaches, the study suggests that the tablet PC technology may facilitate future development of more flexible approaches.

Introduction

A number of studies have examined factors that may influence lecturer adoption of new technologies in educational environments (Abrahams, 2010; Elzarka, 2012; Rogers, 1983; Schoepp, 2005), including interactions between changes in pedagogy and discipline content (Harris, Mishra, and Koeler, 2009). Annan (2008, p. 16) noted that faculty “must be convinced of the relevance of the technology to what they do in the classroom if they are to be convinced to change their current practices”. However, the focus here is not directly on the teacher viewpoint, but on the student viewpoint; of their perceptions of teacher use of different technologies for the presentation of mathematically based material in lecture theatres and classrooms in a tertiary campus environment.

Traditional delivery modes in classroom environments have involved the use of handwritten material on a board in association with what have been described as pedagogically conservative lecture approaches. The term “chalk and talk” is commonly used to describe such teaching methods, which have been criticised as being transmissive, teacher centric and ineffective (Bates, 2015). However, these criticisms have generally been made without consideration of the disciplines involved, and Fox and Artemeva (2011) determined that in the context of mathematics education what they termed a “chalk talk” approach can be “pedagogically interactive, meaningful, and engaging” (p. 87), even when it is essentially transmissive. A valuable component of the lecture can be the explicit modelling of expert thinking (Bates, 2015; Bergsten, 2007; McKeachie & Svinicki, 2013) which, in the context of mathematics education, Greiffenhagen (2008) described as “situations in which an experienced mathematician demonstrates mathematical expertise to novices as an important part of their progressive induction into professionally competent autonomous mathematical practice” (p. 11).

Although writing boards (blackboards or whiteboards) have remained a preferred delivery technology for many university teachers of mathematics disciplines (Greiffenhagen, 2014), the centralisation of responsibility for the management of teaching rooms in many institutions has encouraged the development of standardised technologies in generic rooms. The data projector, connected to a standard desktop computer, has become a standard configuration in many university teaching spaces (AETM, 2015), including in the study institution, with less emphasis being placed on the provision of large-scale traditional writing boards. However, the standard computer, with only keyboard and mouse, does not support handwritten inputs, and the use of software such as PowerPoint to display slides of prepared material has become common even in the mathematics lecture. The document camera with data projector is now a recommended option for large and medium university learning spaces (AETM, 2015), providing an option (and sometimes the only option) for the display of handwritten material. More recently the development of digitisers, either within stand-alone monitors or incorporated in devices such as the pen-enabled tablet PC (penTPC), has provided another option for the projection of live handwritten material (Maclaren, 2014).

In the context of this study the introduction of technologies has not primarily involved changes to traditional pedagogical approaches, and might be seen as facilitating their continuance. However, the purpose of this study is not to endorse any particular pedagogical approach, but to examine how technologies can be used to support any approach requiring the presentation of live handwritten material in a classroom (and potentially, online) environment. Although lecturers will have their own personal preferences for delivery methods and technologies, formed by their prior experiences, this study examined whether students share these views.

Study approach

This study was conducted as part of an ongoing design-based research (DBR) project, which aims to guide the introduction and use of penTPC technology for the teaching of mathematically intensive (MI) disciplines in a university environment. The rationale for the project approach is encapsulated in the description of DBR by Anderson and Shattuck (2012, p. 16): “Being situated in a real educational context provides a sense of validity to the research and ensures that the results can be effectively used to assess, inform, and improve practice in at least this one (and likely other) contexts.”

Using the DBR terminology of Sandoval (2014), in this project there is an underlying conjecture that the penTPC can be used by lecturers in ways that enhance learning and engagement in MI disciplines; that this enhancement would derive from the affordance of the penTPC interface to better facilitate communication of non-linguistic content (Oviatt, Cohen, Miller, Hodge, & Mann, 2012, p. 22:2); and that developments need to proceed with an understanding of what is actually happening in relevant educational settings, and why it is happening (Selwyn, 2010, p. 70). From a pragmatic perspective, the fact that the penTPC is already being introduced within current institutional contexts, but without a centrally managed development plan and without guidance of a clearly articulated theoretical framework, provides impetus to articulate appropriate design conjectures and connect the embodied tools, tasks and practices, and mediating processes with appropriate theory.

Although an ongoing concern of the DBR project includes how the device may enable alternative pedagogical approaches, and how they and their associated good use practices might be promulgated, the focus of this initial study is more exploratory. It aims to identify what is happening, and what might be developed as good or desirable practices, within current pedagogic approaches.

Students from six distinct (in date, time and/or location) class sessions involving six lecturers teaching five different subjects within an Australasian university were surveyed in 2015, with ethics approval granted by the university ethics committee. The selected sessions represented a convenience sample, based on timetabling and lecturer availability, from sessions in which the lecturer was using a penTPC in teaching MI engineering subjects. The sessions covered a range of levels, from first-year to third-year undergraduate level, with subjects including both general engineering mathematics and more specialised discipline areas such as mechanical engineering design and control engineering. The lecturers involved had varying levels of experience in the use of a penTPC, from those in their first semester of use to those with over three years of experience. The students in the classes surveyed would have had prior experience with a range of delivery technologies (including traditional whiteboard, document cameras and PowerPoint, as well as the penTPC), although not all would have had experience with all those technologies. Students would also have experienced variations in different classes in how a lecturer may have used specific technologies, and in lecturer expertise with those technologies. Students were asked to give feedback based on the range of their experiences (across class sizes, rooms, subjects and lecturers), and not just on the experiences in that one session (or class) in which they were surveyed.

At the conclusion of the selected sessions students were invited by the researcher, who was not teaching the class, to complete an optional anonymous paper-based survey. A paper-based survey (rather than an online questionnaire) was used in expectation of achieving a high response rate, which was attained, with the 480 survey returns representing over 95% of students present in the sessions. Students were given the option to complete and return survey forms outside of the session, but no further forms were returned outside the session in which they were distributed.

The aspects of the survey that are reported in this paper relate to the questions that asked the students their perception of the effectiveness of five classroom presentation technologies: basic PowerPoint; PowerPoint with live handwritten annotations (penTPC with PowerPoint); whiteboard; pen-enabled tablet PCs used to develop handwritten notes in OneNote (penTPC with OneNote); and document cameras. All but the whiteboard option involved projection of the material using a data projector and screen (DPSc). Students rated the perceived effectiveness of each mode on a 5-point Likert-style scale (*very ineffective/very poor; ineffective/poor; average; effective/good; very effective/very good* or *N/A, no opinion*), using their own interpretation of these terms, with analysis focusing on comparative ratings. Primarily non-parametric quantitative methods were used in the comparative analysis of effectiveness ratings and are described in detail in the following section.

As appropriate to the DBR approach, the study sought not just to identify quantitative differences in student ratings of modes, but to gain an understanding of possible reasons behind those ratings, so as to guide policy development. Thus, students were also invited to comment, in a three-line free text area, headed “Comment (like/dislike)” following each individual effectiveness rating. As with “effectiveness”, the terms “like/dislike”, were not formally defined but left to student interpretation. As apparent in the nature of their comments, student expressions of likes/dislikes were generally related closely to, and interpreted in the context of, their perceptions of mode effectiveness, and vice versa.

Not all students provided comments, and where they did, the comments varied from single words to a few sentences, with a short phrase the most common.

A thematic analysis method was applied in the analysis of comments, involving six phases as described by Braun and Clarke (2006). Firstly, all responses were transcribed verbatim into Excel and examined (Phase 1) and an initial set of categories established within each mode (Phase 2). Many comment phrases were explicit in meaning (for example, "can't see" or "out of focus"), and these guided establishment of common functional categories. Spreadsheet columns were established on the basis of these categories, and text responses entered into appropriate columns. Thus, full descriptions were retained along with numeric summary data (or words with numbers, as advocated by Miles and Huberman, (1994, p. 11), facilitating the ongoing search for and definition and review of themes (Phases 3, 4, 5) within grouped column categories. Identified categories and themes (Phase 6), together with a synthesis of quantitative and qualitative data, are reported in the analysis and conclusions sections.

Comparison of effectiveness ratings

A summary of student effectiveness ratings of the different modes, showing percentages and response counts for ratings within each mode, is shown in Table 1. For ease of referencing, a numerical code was assigned to each category, with -2 as very poor/very ineffective, -1 as poor/ineffective (and collectively, as negative ratings), with 0 as average, and (collectively as positive ratings) 1 as good/effective and 2 as very good/very effective. The data in Table 1 is displayed in comparative stacked percentage column charts in Figure 1. To aid visual comparisons between modes and emphasise the nature of differences, the vertical position of bars in the chart is adjusted to centre the average effectiveness categories on a common datum line. Thus, for each mode, the portion of the bar above the datum represents the proportion of students giving the mode a positive rating plus half of those assigning an average rating, and the portion below the datum represents the percentage of students who assigned a negative rating plus half of those assigning an average rating.

The percentages of students who assign a positive rating and percentages who assign a negative rating are listed by mode in Table 2 and may be visualised in Figure 1 as the top two segments and bottom two segments, respectively, of each bar. Figure 1 shows an increasing preference from standard PowerPoint (31% positive), to document camera (41% positive), to whiteboard (61% positive), and then to the penTPC using PowerPoint with annotation (73% positive), and with penTPC with OneNote software (84% positive) the most preferred option. Standard PowerPoint is the only mode that does not incorporate live handwritten material.

Table 1. Ratings of effectiveness by delivery mode

		PowerPoint		Document Camera		Whiteboard		penTPC with PowerPoint		penTPC with OneNote	
		n	%	*n*	%	*n*	%	*n*	%	*n*	%
Positive	2 very good/ very effective	34	8%	49	13%	115	26%	116	26%	195	41%
Positive	1 good/effective	103	23%	108	28%	153	35%	211	47%	203	43%
	0 average	193	43%	143	37%	111	25%	101	23%	54	11%
Negative	-1 poor/ineffective	81	18%	53	14%	43	10%	14	3%	8	2%
Negative	-2 very poor/ very ineffective	33	7%	33	9%	19	4%	6	1%	12	3%
	Total responses	444	100%	386	100%	441	100%	448	100%	472	100%

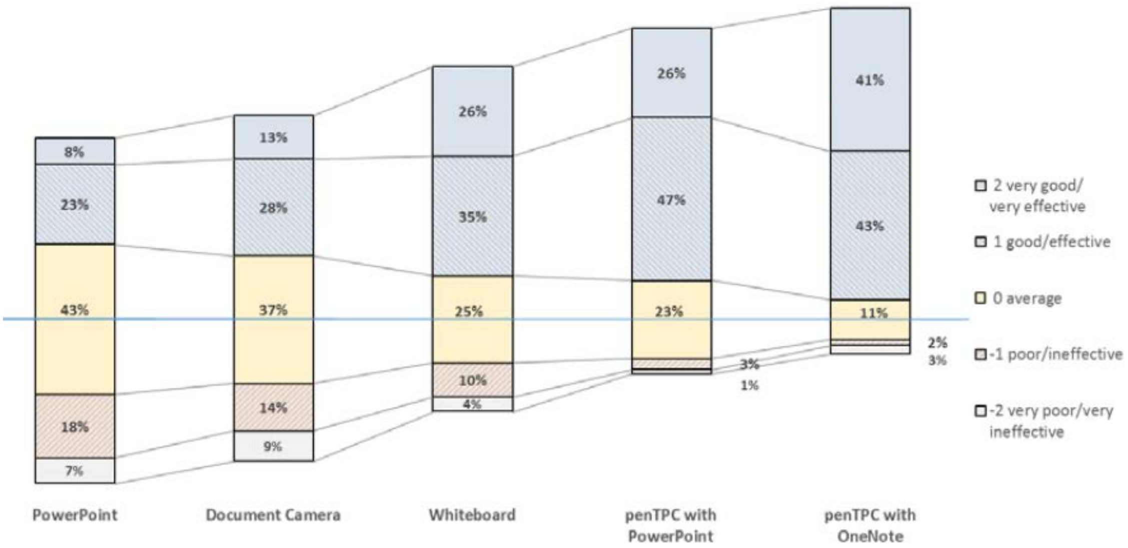

Figure 1. Student ratings of mode effectiveness. Bars divisions show the breakdown of ratings for each technology mode as percentages (rounded). Bar vertical position is adjusted to align the midpoints of the average rating category.

A more detailed analysis was carried out using the Marascuilo procedure (Marascuilo, 1966; Prins, 2013) focusing on the differences in proportions of positive ratings for modes, as listed in Table 2. Results of pairwise comparisons using R software (Bedford, 2013; R Project, 2015), shown in Table 3, determined that all differences were significant at a 99% confidence level except for the difference between PowerPoint and document camera modes, which was significant at a 90% level.

Table 2. Summary of ratings by mode

	PowerPoint		Document Camera		Whiteboard		penTPC with PowerPoint and annotation		penTPC + OneNote	
	n	%	n	%	n	%	n	%	n	%
positive rating 1 effective 2 very effective	137	31%	157	41%	268	61%	327	73%	398	84%
negative rating -1 ineffective/ -2 very ineffective	114	26%	86	22%	62	14%	20	4%	20	4 %

Table 3. Marascuilo procedure analysis

Pairwise comparisons of the percentage of students assigning a positive (+1 or +2) rating. Observed differences that exceed the critical value at the designating confidence level are indicated as significant (**Y**); shaded cells indicate significance at a 99% confidence level.

	Document Camera	**Whiteboard**	**penTPC with PPT**	**penTPC with OneNote**
PowerPoint	Obs. Diff = 9.8% Crit Val $_{99\%}$= 12.1% **N** Crit Val $_{90\%}$= 9.3% **Y**	Obs. Diff = 29.9% Crit Val $_{99\%}$ = 11.6% **Y**	Obs. Diff = 42.1% Crit Val $_{99\%}$=11.1% **Y**	Obs. Diff = 53.5% Crit Val $_{99\%}$=10.0% **Y**
Document Camera		Obs. Diff = 20.1% Crit Val $_{99\%}$ = 12.4% **Y**	Obs. Diff = 32.3% Crit Val $_{99\%}$= 11.9% **Y**	Obs. Diff = 43.6% Crit Val $_{99\%}$= 11.0% **Y**
Whiteboard			Obs. Diff = 12.2% Crit Val $_{99\%}$= 11.4% **Y**	Obs. Diff = 23.6% Crit Val $_{99\%}$ = 10.4% **Y**
penTPC with PowerPoint				Obs. Diff = 11.3% Crit Val $_{99\%}$ = 9.8% **Y**

Effect size

Attention is now directed at determining the practical importance of the differences, as measured by effect sizes (Coe, 2002). In this context we are concerned whether the differences between ratings of alternative technologies are meaningfully large enough to justify a preference for one technology over another. For this ordinal data, Cliff's Delta (Cliff, 1993) is used as an appropriate measure (Grissom & Kim, 2005, p. 107; Hess & Kromrey, 2004; Kraemer & Kupfer, 2006; Peng & Chen, 2014; Romano, Kromrey, Coraggio, Skowronek, & Devine, 2006). Cliff's Delta is also known as the "dominance measure of effect size (DM)" (Grissom & Kim, 2005), and as the success rate difference (SRD) (Kraemer & Kupfer, 2006). The latter terminology (SRD) is used here, with values listed as percentages (rather than proportions) to aid interpretation (Brooks, Dalal, & Nolan, 2014; Knapp, 2009) and allow the values to be directly related to the percentage values in the Tables 1 and 2 and Figure 1. SRD evaluates the effect size in terms of estimates of two proportions: the proportion of observations in which a rating of one mode is higher than an alternative P(Y>X), minus the probability that it be lower P(X>Y) (Grissom & Kim, 2005). It describes an overall net benefit (or "success") of one approach over the other.

An SRD% value of 0% indicates there is no overall effect in using different approaches, (meaning that *on average*, there is no expected difference between mode ratings). An absolute value of 1 (|SRD%|=100%) would indicate the mode is preferred over the other by all respondents; the closer |SRD%| is to 100%, the stronger the effect, with the sign indicating the direction of the preference. In this study SRD values are calculated using a paired case analysis, comparing for each student their rating of one mode with their rating for the other mode (rather than comparing one student's ratings across all other students). This use of a paired data approach reduces potential effects of different interpretations of effectiveness and the rating scale by students; the analysis reflects the individual student's preferences for one mode over another, rather than quantifying their absolute ratings.

Results of the calculations for SRD using Rogmann's ordinal dominance statistics (ORDDOM) package (Rogmann, 2013) for R statistical software are displayed in Table 4, together with the two component probabilities, P(Y>X) and P(X>Y), as percentages. To aid interpretation, effect sizes in Table 4 have been categorised (and shaded) as small (**S**: SRD% < 10%), medium-small (**MS**: 10% ≤ SRD% < 25%), medium large (**ML**: 25% ≤ SRD% < 50%), and large (**L**: SRD% ≥ 50%). Table 4 also gives 95% confidence intervals for the effect sizes, as calculated using ORDDOM, based on an analysis by Feng (2007; Feng & Cliff, 2004).

Table 4. Effect size: Success rate difference (SRD%)

	Document Camera	Whiteboard	penTPC with PowerPoint	penTPC with OneNote
PowerPoint	SRD% = 9.5% **S** (37.5% - 28%) C.I: 1%–18%	SRD% = 31% **ML** (54% - 22%) C.I: 23% – 39%	SRD% = 56% **L** (62% - 6%) C.I: 50% – 61%	SRD% = 60% **L** (67% - 7%) C.I: 54% – 66%
Document Camera		SRD% = 23% **MS** (43% - 20%) C.I: 15% – 31%	SRD% = 38% **ML** (51% - 13%) C.I: 31% – 45%	SRD% = 55% **L** (60% - 5%) C.I: 49% – 60%
Whiteboard			SRD% =12% **MS** (39% - 27%) C.I: 5% – 20%	SRD% =30% **ML** (45% - 15%) C.I: 23% – 36%
penTPC with OneNote				SRD%=20% **MS** (36% - 16%) C.I: 13% – 26%

Cell key: Each cell shows SRD% together with component probabilities as percentages (P(X>Y)-P(Y>X)) and 95% confidence intervals for SRD%.

Effect size	SRD% < 10% **S** Small effect	10% ≤ SRD% < 25% **MS** medium-small	25% ≤ SRD% < 50% **ML** medium-large	SRD% ≥ 50% **L** Large

The effect sizes confirm the penTPC with OneNote mode to be the most favoured, with a 60% SRD (evaluated as the percentage who rated this mode better than the PowerPoint mode, minus the percentage who rated it worse) over the PowerPoint mode, a net 55% preference over the Document Camera mode, and a net 30% preference over the whiteboard mode. The penTPC with OneNote mode also showed a net 20% preference over the other penTPC mode (penTPC with PowerPoint). These effect sizes are also confirmed as statistically meaningful, as none of the confidence intervals include zero.

Although it is recognised that there are arguments against using interval scales and parametric methods with ordinal data, a reasoned assignment of an interval scale to the ordinal categories here can generate a useful raw score measure and aid interpretation and communication of results in the context of the study (Baguley, 2009; Velleman & Wilkinson, 1993). We are concerned here with making judgements on quality improvements, and a scale that gives a stronger positive emphasis to a desired goal of “very good” (rather than just “good”), and a stronger negative emphasis to “very poor” (rather than just “poor”) may be useful. Applying a consistent interval scale of -2, -1, 0, 1, 2 across all the modes, the mean ratings for the modes were calculated and are shown in Table 5 together with a 95% confidence interval for these means, the standard deviation, and sample size for each mode. These means, with a 95% confidence interval, are displayed in the chart in Figure 2.

Table 5. Parametric summary statistics for modes

Note. Expressed as category units, with categories assigned values -2, -1, 0, 1, 2)

	PowerPoint	**Document Camera**	**Whiteboard**	**penTPC with PowerPoint**	**penTPC with OneNote**
Mean x	0.05	0.23	0.68	0.93	1.19
C.I. (95%)	(-0.4 – 0.15)	(0.12-0.34)	(0.58-0.79)	(0.85-1.01)	(1.11-1.27)
Std devs	1.0	1.1	1.1	0.85	0.89
n	444	386	441	448	472

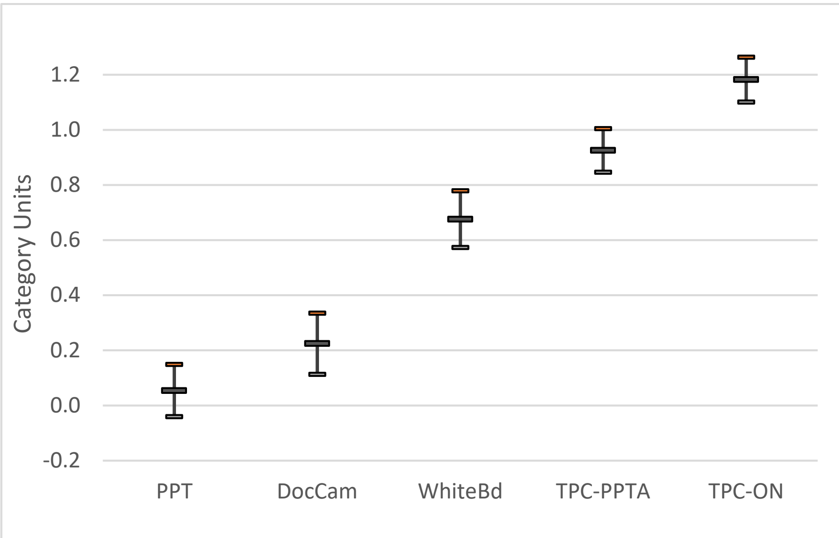

Figure 2. Mean effectiveness rating by mode (with 95% C.I.). (Note: Based on category values -2, -1, 0, 1, 2.)

Differences between the mean rating for each mode, denoted as *Δm* in Table 6, provide a simple comparative measure of effect size, measured in units of “number of categories” of shift. As expected, Table 6 reveals a similar relationship to that shown in the ordinal analysis. The penTPC with OneNote mode is rated best, being more than one category unit better than PowerPoint, and on average one-half a category improvement over whiteboard. PowerPoint is rated the least effective, and the document camera only slightly better.

Table 6. Differences between means (Δm) measured in category units

	Document Camera	Whiteboard	penTPC with PowerPoint	penTPC with OneNote
PowerPoint	Δm = 0.17 **S**	Δm = 0.63 **ML**	Δm = 0.88 **L**	Δm = 1.13 **L**
Document Camera		Δm = 0.46 **MS**	Δm = 0.71 **ML**	Δm = 0.96 **L**
Whiteboard			Δm = 0.25 **MS**	Δm = 0.50 **ML**
penTPC with PowerPoint				Δm = 0.26 **MS**

Key	$\Delta m \leq 0.25$ **S** Small effect	$0.25 \leq \Delta m < 0.50$ **MS** medium-small	$0.50 \leq \Delta m < 0.75$ **ML** medium-large	$\Delta m \geq 0.75$ **L** Large

Analysis of student comments and relationship to ratings

As discussed in the Study approach section, student comment responses associated with each mode rating were analysed to identify key categories/themes and these are shown in a quantitative summary in Table 7. There were varying levels of response in the comment sections for each mode, and while most respondents mentioned only one issue, some responses covered more than one issue (with totals shown as response categories in Table 7). An initial categorisation of comments as to whether they were negative, positive, conditional (depends) or indeterminate (n/a) showed an ordering of modes broadly matching the preceding ratings order. While in the following discussion some emphasis is given to the more frequently and explicitly occurring comments, attention is also given to individual comments that appear to capture “something important in relation to overall research question” regardless of frequency (Vaismoradi, Turunen, & Bondas, 2013, p. 403). The absence of explicit mention of a particular theme within a mode may also carry significance, with motivation for comments perhaps arising from comparative expectations of a mode rather than absolute judgements. Thus, the comments are used primarily to seek an understanding of the potential reasons influencing student effectiveness ratings, and as indicators of how modes might be improved, rather than as having direct quantitative significance for mode comparisons.

Table 7. Respondent comments by mode and category

	Respondents	No. of comments (see note)	Tenor of responses (negative/positive)				Key categories/themes Doing/ engaged		Can see clearly		Can read hand writing		Interface		Notes access	
			-	+	*depends*	n/a	-	+	-	+	-	+	-	+	-	+
PowerPoint	87	95	60 69%	23 26%	7 8%	5 6%	44 51%			2 2%			8 9%	11 13%		5 6%
Document Camera	63	68	44 65%	6 9%	10 15%	8 12%	1 1%	1 1%	27 40%		1 1%	1 1%	7 10%			
Whiteboard	122	130	57 47%	67 55%	4 3%	2 2%	2 2%	40 33%	47 39%	2 2%	3 2%	2 2%	3 2%	4 3%		
penTPC with PowerPoint	48	50	6 13%	38 79%	6 13%	0 0%	2 4%	27 56%					1 2%	3 6%	1 2%	3 6%
penTPC with OneNote	122	137	38 31%	93 76%	3 2%	3 2%	7 6%	25 20%		19 16%	15 12%		5 4%	5 4%	6 5%	22 18%

Note. Some respondents made comments covering more than one category. Percentages of responses are calculated in terms of counts of respondents, so totals of individual percentages can add to > 100%.)

PowerPoint

Students in all sessions consistently rated the use of basic PowerPoint with prepared slides as the least effective mode. There were 95 classified comments from 87 respondents. The majority of the responses (60 from 69% of respondents) were essentially negative, with 44 comments (51% of respondents) concerning lack of interactivity and engagement (and absence of annotation compared to the penTPC with PowerPoint mode), identified in Table 7 as a common theme of doing/engage:

> Lack of engagement; not interactive enough and too easy to stop paying attention; do more example calculations regarding topic on slide; calculations [needed to] get info across; useful if you miss a lecture but boring in class; flicking through powerpoints rapidly is pointless; reading and not going through (material) is what we can do at home; too much info on the screen while the lecturer is talking; sometimes too much detail;

> lecture slides are rushed; sometimes lack the necessary details; unless used in conjunction with other method, it is useless.

These comments echo the widespread criticism of PowerPoint expressed in a range of other studies across a range of disciplines (Berk, 2011; Craig & Amernic, 2006; Levasseur & Kanan Sawyer, 2006; Mann & Robinson, 2009; Savoy, Proctor and Salvendy, 2009). The students in the study make it clear that basic PowerPoint does not meet their need to observe the lecturer dynamically demonstrate the reasoning processes underlying mathematical problem solving (Maclaren, 2014). The importance of seeing mathematics being done is also indicated by comments (5 or 6%) that were supportive of the mode, but not for MI subjects:

> Good for (some subjects) but not for maths; good for [non-mathematical] subject.

There were 23 comments (26% of respondents) identifying positive factors, mostly related to the structure and form of the presented material (interface – 13% of respondents), and as a source of notes (notes access – 6% of respondents):

> Clear and structural; everything is there and clearly shown; well prepared; the advantage of this is that the information is layed out nicely; good for showing notes that lecturer can talk about; everything is there and clearly shown.

However, a number commented negatively on the slide format, suggesting a single slide often carried too much detail to be copied and absorbed in the time it was visible. There were also conflicting comments, that slides "sometimes have too little detail", which might be reconciled by consideration of the subject material and the pace of presentation. If the lecturer is modelling expert thinking and developing complex procedural techniques, then full detail of the steps involved, presented at a slow pace, is essential. If factual information is presented at high density and rapidity (for example, flicking through slides containing large amounts of text), the student will have little time to absorb details. However, providing too little detail, and reducing textual information to bullet points, can remove essential context (Tufte, 2003). Finally, as one student states, reading information is something they can do outside class, and there are arguably better formats than standard PowerPoint slides for providing that information and, as revealed here, better modes for in-class presentation.

Document camera

Although the document camera is a standard and recommended feature in many universities for larger lecture rooms (AETM, 2015, p. 59), it is not generally available in smaller classrooms in the study institution. In larger rooms with minimal or no whiteboard capability, the document camera may be the only available presentation technology that supports handwriting. However, students judged the document camera to be the least effective of the handwritten modes and only slightly more effective than basic PowerPoint. Unlike other handwritten modes, there was little comment on the positive influence of mode on pace and engagement. Negative comments (44 from 65% of respondents) dominated, with most of those (27 or 40%) concerning the ability to see the material clearly (particularly focus):

> Out of focus; blurry; not very clear; In most cases visibility issue; Unclear, hard to read.

Although focus issues may be particular to the models of document camera installed in the study institution, there are factors of the interface inherent in the technology that are generic to all such devices: when in use the hand will be visible and at times may obscure, and distract from, the written material; the visible writing area, or field of view, is generally limited and requires frequent physical rearrangement of the writing surface (usually paper), with the loss to view of previously written material. Seven (10%) respondents identified interface issues, such as:

> Hand is always in the way …; gets confusing switching between bits of paper and use of figures is difficult; viewing area too small, lose track, can't follow; hand can get in the way and limited visibility time; hard to read handwriting sometimes.

As with all handwritten approaches, there can be considerable variation between lecturer in their technique and handwriting capability, with individual comments both praising and lamenting handwriting techniques. Although there may be situations where the document camera has particular uses, such as in projecting views of physical artefacts, in this study environment at least, its inability to deliver material that could be clearly read overrode any potential benefits.

Whiteboard

The whiteboard is a traditional technology familiar to both students and staff for which usage approaches have been refined over time, and which has become a standard technology for the classroom teaching of mathematical disciplines (Fox & Artemeva, 2011). There were 130 comments from 122 students. Just over half of the respondents (67 or 55%) offered a positive comment, with most of those concerning pace of delivery and full exposition of problem-solving steps, as inherent in a handwritten approach:

> Good if its done step by step and not too fast; includes important steps; it keeps the pace of the lecture reasonable and not too fast; like full working,

> don't like bullet points; effective as student has time to think during process; good as it (is) slower and we can take notes at the same pace as lecturer; engages the student very well.

Although there were some comments, both positive and negative, about the quality of lecturer handwriting, it was (as with the document camera) not being able to see the content clearly (47 or 39%) that was a critical negative issue, even for those who otherwise liked the mode:

> Difficult to see; Often hard to see; cannot see whiteboard; Very hard to read; writing is often too small; difficult to see from the back; cannot see well if you sit at the back; sometimes its hard to read and not all the whiteboard markers work properly; Red pens are hard to read!!!!!; Ink too light/bright and can't see from far; good but sometimes hard to read; Great as long as the room is small enough to see the whiteboard; Very good to see working done but cannot be seen by all over class; I like it however the pens are often light or thin.

Visibility issues are a particular concern in larger rooms, from the back or from a side. Detailed recommendations concerning the visibility of material from a distance have been produced in relation to signage and projection of visual displays (AETM, 2015; Cai & Green, 2009; van der Zanden, 2014). Factors addressed include the dimensions of the displayed elements (particularly element height and the width of the strokes forming the elements) in relation to distance from the material, viewing angles, illuminance, contrast between text elements and background, and the use of a positive contrast (dark text on light background) or negative (light text on dark background). It appears likely that these are issues that also need to be considered in presenting material on a whiteboard.

Within the study university, the lack of substantive whiteboard space in many rooms has been commented on by staff, and might be argued to have led to a sub-optimal experience of whiteboard mode for both lecturer and student. Some universities have boards that are able be raised after having been written on, but they are not available in the study university. Although vertically moveable boards allow a larger amount of material to become or remain visible after writing and before erasure, they do not address the issue of material being obscured while it is being written, and the fundamental issue of visibility from a distance remains. In some newer lecture theatres in the study university there are in fact no permanent whiteboards, and this has become a factor pushing lecturers toward the use of digital modes.

PenTPC with PowerPoint and handwritten annotations

The penTPC, used in conjunction with a data projector and associated screen, has been identified as a potential digital alternative to the traditional whiteboard (Maclaren, 2014). This survey intended to distinguish two software alternatives for use with a penTPC: one utilising pen annotations within PowerPoint (with PowerPoint slides forming the writing board) and the other using the pen within OneNote (with OneNote pages forming the writing board). However different developments in lecturer use of the penTPC have resulted in a range of variations in usage; in some instances, lecturers have made use of two data projectors (available in a few rooms), using one projector for PowerPoint (driven from a standard desktop PC) and the other projector for live developments with OneNote; in other instances, lecturers have used a whiteboard in conjunction with projecting standard PowerPoint. It is apparent that students may have had a range of variations in mind when rating the effectiveness of PowerPoint with handwritten annotations, and this needs to be kept in mind when examining student comments.

Students rated the use of the penTPC with live annotation of PowerPoint slides as the second most effective mode, being more effective than whiteboard mode and less effective than the use of the penTPC with OneNote. There were 50 comments from 48 students on the use of annotation with PowerPoint, with the majority (38 or 79%) being positive. Many comments were related to the additional functionality (over standard PowerPoint), with annotation allowing dynamic development of material and calculations providing for better engagement (doing/engaged – 27 or 56% of respondents). Typical comments were:

> Better than std ppt and feels more interactive; Annotations are important; we need in class annotation to help understand the concepts; Annotations from class make things easier to understand; Without annotation some slides are hard to understand the second time; very useful to follow working through; I find annotation very important, when a lecturer can write examples, and explain problems; Helpful as they explain as you go; allows me to see step by step solutions which help with understanding; This is the most engaging and easiest to see.

Student comments indicate that the higher rating given for this mode over standard PowerPoint may be attributed to the reintroduction of a live handwritten mode. Rating this mode as more effective than whiteboard mode may be attributed to enhancements in visibility. Unsurprisingly, students wanted class sessions to include live development of mathematical processes but in a format that was clearly visible. Negative comments were related to not always having post-class access to material that included the annotations, and the format (of discrete slides) restricting viewing of earlier material:

> Depends on subject as long as the updated slides are available for download; Adds detail to slides but can't see the previous notes.

PenTPC with OneNote

The last mode considered involves the use of Microsoft OneNote in conjunction with a Tablet PCs and a data projector, and was the highest rating mode. This mode is of particular interest as it is becoming a common approach, acting as a digital whiteboard replacement (Maclaren, 2014) in many classes. It can provide essential affordances for handwritten input, as well as a suitable organisational structure that can be tailored to suit provision of class notes. The software can provide an effectively unlimited writing space on each page, ready navigation between and within pages (including zooming in and out of details) and customisable pens that allow different stroke widths and colours. It allows a combination of live handwritten material, prepared graphics and text and images to be delivered in conjunction with other software and video.

There were 137 categorised responses from 122 respondents on this mode, with 93 positive comments (76% of respondents). Key references were to dynamic engagement (doing/engaged – 25 comments from 20% of respondents), visibility (19 from 16%) and note provision (22 from 18%). Sample comments from each group are:

> OneNote way best, as I could understand steps and method; very useful to follow working through; I like it because it gives a clear understanding of the material; easily accessible notes online and step by step process helps with learning.

> Can see the board wherever you sit; easy to read and always high contrast (pen can't run out of ink); Same as the board but more clear and bigger to see.

> Good because notes can be uploaded; Great if uploaded to AUTonline; Lecturer can post it up later; I like this best because it allows the lecturer to record the lessons with ease.

Some negative comments reflected capabilities that were not being utilised by some lecturers:

> Would be better if the lecturer's notes were uploaded for students access online.

These comments again illustrate that students want steps involved in mathematical procedural thinking to be developed live, and (obviously) need that material to be clearly visible from anywhere in the room, and are concerned to have access to notes outside the class.

There are a number of issues related to notetaking by students and note provision by lecturers, and changing expectations of and from students and lecturers of the types of activities to be conducted both inside and outside the classroom. The penTPC with OneNote mode provides ready access to a range of options for recording, and although at this time there is no consistent approach by lecturers, student comments make it clear that they consider access to a record of the lecturer notes as a valuable feature where it has been made available. As with all handwritten modes, there remain issues related to the legibility of the lecturer’s handwriting and expertise in using the technology, and these accounted for the majority of the negative comments (15 from 12%, of respondents):

> Only good if the lecturer is able to use their tablet, has good handwriting. Handwriting need to be better; As long as legible. Handwriting a factor.

Student comments also recorded the fact that the mode is not limited to presenting handwritten material:

Can bring in figures and tables into notes.

Singer and Smith (2013, p. 470) reported on the importance of using multiple forms of representations in instruction, including “realistic (picture or text), diagrammatic (free body diagram) and symbolic (mathematical)“ representations. Oviatt (2013b, p. 61) stressed the importance of using interfaces that support “expression of non-linguistic representations, including diagrams, symbols, numbers, and informal marking”. The tablet PC environment provides for these combinations of digital representations that are difficult to support in keyboard-based digital interfaces in conjunction with traditional handwritten board technologies. Although many smaller classrooms are equipped with both data projection screens and whiteboard in some form, there are often conflicting requirements in both placement and lighting that can make use of the two modes together less satisfactory.

Within the classroom (and outside), access is no longer limited to what has not already been erased. Although not continuously in the field of view, previously written notes (even from earlier sessions) can be scrolled back into visibility by the lecturer at any time, and parts of interest can be zoomed in on to allow inspection of detail. As the following comment shows, in one class (at least) a lecturer has been making use of the capability to share OneNote notebooks live, providing students with access to the notes as they are being developed, and providing potential capability for students to use their own devices to independently scroll through material:

> OneNote is a great tool and viewing it live allows me to jump back in time to notes he’s moved on from; One thing I like is how it updates in real time to my laptop, so if he speeds ahead I can go back.

In making their judgement on this mode, students will have encountered lecturers with a range of experience in using the penTPC mode, including a number in their first semester of use. Despite being at an early stage of development, the study has shown the penTPC OneNote mode to have the highest student rating, being judged significantly better than all other modes. Although some common practices are beginning to be observed, the development of guidelines for good practice may further enhance the effectiveness of use of this mode.

Conclusions

Students surveyed in this study, who were being taught MI engineering subjects in a classroom environment, rated the effectiveness of different delivery modes as ordered below (worst to best):

PowerPoint → Document camera → whiteboard → penTPC with PowerPoint→ penTPC with OneNote

These differences between student ratings of modes were statistically significant, and effect sizes were meaningfully large.

Student comments on likes/dislikes suggest that ratings of effectiveness are influenced by placing higher value on teaching technology modes that support the key categories/themes as identified in Table 7:

- enable the display of live, step-by-step development of theory and problem solution (doing/engaged)
- display material in a format that is clearly visible, with legible writing, throughout the class environment (can see clearly), (can read handwriting)

- enable inclusion of other material, such as figures and tables (interface)
- can provide a record of notes that can be made available online (notes access).

The strong student preference for the use of penTPCs as a classroom delivery mode revealed in this study can be explained by the strong support that this mode affords all of these factors. The results suggest that students share the values identified by lecturers of the importance of the explicit modelling of expert thinking as a key component of the teaching sessions. The specific issues of student notetaking in class and lecturer provision of notes (both prior and post a session) in the context of developments in software and pedagogical approaches are also issues identified for further examination as part of the larger design research project to which this survey contributes.

This research has implications across a range of institutional roles and functions. Although student preferences have been clearly established, there are other considerations, including financial issues that need to be considered. If use of penTPC technology is to become a teaching standard, managers will need to ensure that institutional policies and procedures enable all teaching staff engaged in these areas to have access to such a device, particularly given pressure from students for its adoption. Information and computing technology (ICT) support services need to be skilled in supporting this mobile technology, which may have different requirements from desktop PCs. Planned, structured institutional support is essential for successful introduction of new educational technologies (Elzarka, 2012; Schoepp, 2005).

For those in charge of space management and development (estates management), the requirements for the generic classroom may need to change if the tablet PC is to becomes a standard for classroom delivery. The physical layout and height of lecterns and positioning of cables may benefit from redesign to better support tablet writing, and provision of suitable (high definition) data projectors and screens in all rooms becomes essential. The document camera might be determined to be unnecessary as a standard item; even where there is the need to project views of physical artefacts, a stand to support a tablet equipped with a suitable web camera might be sufficient.

This study looked at delivery modes for MI subjects in a traditional classroom environment. The importance placed on demonstration of procedural development using handwritten approaches has been a factor that has supported the ongoing use of the traditional lecture style format in the mathematics classroom. It is apparent from this study that the students regard the penTPC as providing an effective and preferred technology for maintenance of this approach, especially within larger classrooms. It is also apparent that there is scope for refinement in the techniques for use of the technology that may be aided by the development of guidelines for its effective use.

Puentedura (2010) described technology as having the potential to be used in a progression, at a level of substitution, augmentation, modification or redefinition (abbreviated as SAMR). Models such as TPACK (Harris et al., 2009) investigate more complex interactions between pedagogy, content knowledge and technology, often involving the use of technology by students, rather than just by lecturers. However, in this study the penTPC was used by lecturers as a substitute for, or a functional improvement over, the whiteboard, without substantive changes in pedagogy. To recast the earlier quote from Annan (2008, p. 16), it appears from this study that the introduction of the technology may be facilitated because faculty and students are “convinced of the relevance of the technology to what they [currently] do" and because there is no immediate need "to change their current practices".

However, enabling faculty to become fluent in the use of a technology for familiar academic tasks and even personal uses, as advocated by Elzarka (2012), may make it easier to subsequently introduce pedagogical changes that take fuller advantage of the affordances of the technology. By providing support for delivering and recording handwriting in all forms of a digital environment, the penTPC has the potential to enable substantive modification and redefinition of learning and teaching approaches, with reconsideration of what is best done in class and what is best done outside of class. When students, and not just the lecturers, have guaranteed access to these devices the scope for change is further enhanced.

Thus, it is the capabilities of the technology to redefine how MI classes are taught in the modern university, by enabling interactions that have previously been possible only within the classroom to be conducted within online environments, that may provide the most compelling arguments for its adoption.

References

See References section at end of Thesis.

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CHAPTER 6 / ARTICLE 3 - MAKING THE POINT: THE PLACE OF GESTURE AND ANNOTATION IN TEACHING STEM SUBJECTS USING PEN-ENABLED TABLET PCS

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Abstract

The teaching of STEM subjects, and Engineering and Mathematics in particular, involves the use of a wide range of representational forms, including equations, diagrams, sketches and graphs, supported by speech and gestures. In the traditional face-to-face 'board' based classroom, the integration of writing, speech and gesture has been a key feature of pedagogical delivery approaches.

The pen-enabled Tablet PC (penTPC), used in conjunction with a data projector, allows for the maintenance of a handwritten approach in teaching environments where traditional boards are unavailable or limited. However, it has been suggested that the use of the digital interface imposes restrictions on lecturer movement and gesture, compared to traditional board environments.

This paper examines the adaptations made by a selection of lecturers in using the penTPC in a classroom environment. The study suggests that the use of penTPC technology does not preclude the use of gesture, and that the augmented capability for annotation in conjunction with other digital representations can enhance teaching, particularly of STEM based discipline subjects.

Introduction

> Gestures … are writing in the air, and written signs frequently are simply gestures that have been fixed.
>
> (Vygotsky, 1978, p. 107)

This paper is concerned with the effective use of the pen-enabled Tablet PC (penTPC) as a technology for the teaching of mathematically based subjects, specifically as it may be used by a teacher in the context of a classroom environment. While the lecture as a generic pedagogic device has been widely criticised (Bates, 2015), Fox and Artemeva (2011) have defended its use in the mathematically intensive disciplines where the characteristic combination of writing and talking is seen as providing essential components for developing students' capability. Greiffenhagen (2008) describes the mathematics lecture as where "an experienced mathematician demonstrates mathematical expertise to novices as an important part of their progressive induction into professionally competent autonomous mathematical practice" (p. 11).

An important element of this approach is the use of handwritten modes for the development of material, which establishes a pacing suiting the student acquisition of procedural skills and concepts (Artemeva & Fox, 2011). While the penTPC clearly supports the handwriting component essential in developing traditional mathematical thinking, other components are also involved in face-to-face communication. Gesture has been suggested as playing an important role in teaching and learning (Roth, 2001), with a number of authors noting the importance of gesture in the specific context of developing mathematical thinking (Alibali et al., 2014; Arzarello, 2006; Arzarello, Paola, Robutti, and Sabeba, 2008; Fox & Artemeva, 2011; Goldin, 2010; Radford, 2008). Thus, along with additional affordances of the penTPC, attention needs to be given to the constraints that the device may impose on the way gesture is used (Thomas & Hong, 2013). If, as Yoon, Thomas and Dreyfus (2011) argue, gestures can help to develop advanced mathematical insights "by supporting the creation of virtual mathematical constructs" (p. 891) then it is important to investigate the constraints on use of gesture that may arise in the penTPC environment.

Gestures in the broad sense have been classified in a range of forms, from gesticulation, emblems, pantomime, to sign language, in a succession in which concurrent speech becomes progressively less important in maintaining meaning (McNeill, 2005, p. 5). As a prominent form of gesture, gesticulation has been a major focus for many researchers, such that the generic term gesture is often used in place of gesticulation (McNeill, 2005, p. 5, 2006, p. 3; Roth, 2001, p. 369). McNeill (1992) identified four major types of gesture: iconic (referencing a concrete object); metaphoric (referencing an abstract idea); beat (a rhythmic emphasis); and deictic (pointing, positional). McNeill later (2005, p. 38) proposed that it is better to think of gestures in terms of having dimensions (rather than being of distinct types), with any one gesture potentially exhibiting some or all of the various dimensions to differing extents. This is the approach used here in examining lecturer use of gestures.

While using a penTPC the lecturer is holding a writing instrument in the form of a digital pen. Thus the lecturer has options to make a gesture in a conventional way, in a transient form in the air with hands, or to give it concrete form as a written mark on the screen. These written marks have been termed both "writing gestures" (Alibali et al., 2014, p. 76) and "attentional marks" (Anderson, Hoyer, Wolfman, and Anderson, 2004, p. 569), each assigning emphasis to different aspects of their generation. Classifications of *written*, *oral*, and *gesture* may be used to identify primary registers of communication, or as termed by Bosch and Chevallard (1999, p. 96), and translated in Arzarello (2006, p. 270): *trace* (written), *oral* and *gesture*. Sabena (2008, p. 21) defined gestures in a mathematical setting as including “all those movements of hands and arms that subjects (students and teachers) perform during their mathematical activities and which are not a significative part of any other action” (such as writing with a pen). Thus the term *attentional marks* (rather than *writing gestures*) will be preferred here, locating them clearly as permanent marks within the trace register. Nevertheless, attentional marks share some characteristics of gestures, in that they may at times be dependent for full meaning on other co-existing modes, including previously created functional writing and accompanying speech. However, as Anderson, Anderson and McDowell (2005) noted, there is a critical difference between the ephemeral nature of gestures and the persistence of attentional marks.

It has also been suggested that there are strong linkages between diagrams and gesture, with diagrams suggested as a refined extension of an iconic gesture, in written form. De Freitas and Sinclair (2011) noted the relationship between gesture and diagrams, expanding on the work of Châtelet (2000), and suggesting that diagrams lock or capture gestures. Bunt, Terry and Lank (2009, p. 230) describe how “mathematicians make liberal use of sketches, mathematical expressions and annotations to render abstract mathematical concepts more concrete”, also noting that these representational forms should be viewed as dynamic objects, as “terms in an expression are crossed out, content is added to sketches, and new insights lead to new annotations” (p. 230).

It may be useful to consider attentional marks within a wider context of annotations, just as gesticulation may be considered as a particular form of gesture. Thus annotations may range from non-descript marks (analogous to gesticulations), through universally recognisable signs, such as ticks, circles, underlines and highlights (emblems), to elements within fully structured symbolic languages, such as algebraic equations (sign languages). While annotations may be created concurrently with speech, and some may be dependent on that speech for full meaning, others annotations may establish or maintain meaning independently of speech, and beyond the instant of their creation. Furthermore, just as gestures may be considered as having dimensions (rather than being of distinct types), annotations may have multiple dimensions, potentially serving multiple purposes. Thus the addition or development of functional content in graphs, diagrams and symbolic expressions (such as adding tangents to a curve, labelling points on a diagram, or cancelling terms in an algebraic expression) adds functional content in conjunction with giving timely emphasis to the sequencing of that content.

In a board-based classroom, the teaching of mathematically intensive subjects has developed into a standard and well recognised pedagogical form (Fox & Artemeva, 2011, p. 83; Shulman, 2005b, pp. 53–54). In substituting a penTPC for a board, lecturers are required to adapt this traditional approach according to the affordances and limitations of the technology. Fox and Artemeva (2011) described traditional classroom presentation as a cinematic art that has many elements, including the use of gesture as a natural and spontaneous component of teaching and "enacted in part through the physical positioning of the professor" (p. 91). There are significant interactions between body movements (including position) and forms of gesture and writing, and these impacted by a change from the use of board to penTPC. Thus whole body movements (including positioning within the classroom) are also an important feature examined in this study.

While the use of the penTPC may affect communication in the classroom by constraining the range of movements and gestures used by the lecturer, it also provides other affordances, with increased capabilities for introduction of other digital forms, and interactions with those forms through direct annotation. In recent years the use of software based methods for problem solving and data visualisation has had a significant impact on STEM content knowledge. New discipline procedures and conceptual understandings have been developed that would not be possible without the use of new computing technologies. The capabilities of software to generate visual representations of data have also altered approaches to the interpretation of data and decision making (Campbell & Latulippe, 2015; Goeser & Ruiz, 2015; Hodge & Taylor, 2002). The capability to integrate software output and diagrammatic representations into digital teaching environments, and to annotate directly on them, is arguably now an essential element of STEM education, and an element for which the use of digital pen devices such as the penTPC provide critical affordances.

Singer and Smith (2013, p. 240) have noted the value of using multiple forms of representations in instruction, including “realistic (picture or text), diagrammatic (free body diagram) and symbolic (mathematical)” representations. Oviatt (2013b) stresses the importance of using interfaces that support “expression of non-linguistic representations, including diagrams, symbols, numbers, and informal marking” (p. 61). The capability of the penTPC to provide support for these features is also of interest here.

While recognising that detailed analysis might cover a complex range of interacting resources (as a semiotic bundle, as described by Arzarello (2006)), this study focused on the specific elements as identified by Fox and Artemeva (2011) as occurring in the board-based classroom, but extended to include additional elements available in the penTPC environment. Thus the study sought to identify the broad effect on the nature of multimodal communication, in particular in the use of annotation and the relationship with gesture, resulting from the adoption of the penTPC technology by lecturers and as used in the specific context of the teaching of mathematically intensive engineering courses.

Study Approach

The study involved 7 lecturers who had been using penTPCs in teaching STEM disciplines in a university environment, drawn from a group who participated in pilot projects which provided them with access to a penTPC for teaching, who consented to be studied, and where timetabling constraints allowed access to class sessions. While essentially a convenience sample, the lecturers involved had varying levels of experience in use of a penTPC, from those in their first semester of use, to those with over three years of experience, and the lecture sessions surveyed covered a range of subjects and levels within mathematics/engineering disciplines. One of the lecturers was no longer using a penTPC in the classroom, and had reverted to using a board. While the number of lecturers involved was small, it was considered sufficient to give useful insights into current practices within the university (Nielsen, 2000; Tang & Davis, 1995). The study was approved by the institutional ethics committee.

The study examined the method of delivery used in lectures involving use of the penTPC as the primary classroom presentation device for handwritten material. Video analysis of lectures was conducted with specific focus on the use of gesture and annotation in the classroom situation. The features of the penTPC class session were identified and compared with those of the conventional board classroom, focussing on the co-occurring multimodal elements that were employed by the lecturers. The activities observed in lecture session are first described briefly for each lecture session (Cases), and then analysed collectively, in relation to key elements of the board classroom approach (Fox & Artemeva, 2011).

The opinions of lecturers involved in the use of the penTPC were also surveyed in a questionnaire as part of a wider study (Maclaren, Wilson, & Klymchuk, 2017a). The perceptions of the particular lecturers in this study of the affordances of the penTPC and adaptations required for their use, as recorded in questionnaire comments, are also referenced here and related to their observed practices. These give an indication of the extent to which lecturers have consciously adapted their approach to the affordances of the different environment.

While the analysis and conclusions are drawn from, and relate to, the particular context of this study, there are many aspects that will be familiar to those working in similar environments and that may be used to inform developments in the introduction and use of penTPC technology.

Observations

Case 1: Undergraduate (Yr 1) Engineering Mathematics Lecture

This lecturer was in the first semester of using a penTPC, teaching a first year undergraduate engineering mathematics class. The environment was a medium size tiered lecture theatre, seating 172. Approximately 80 students were present. There was a single data projection screen (DPSc) located at the front, centre of the room.

The lecturer conducted the session using the penTPC as the only presentation technology, with all material handwritten live on the penTPC using Microsoft OneNote software. The lecturer remained standing at the lectern for the duration of the lecture, almost exclusively facing the class, using a lectern-mounted microphone. Lecturer activity alternated between hand writing on the penTPC (developing diagrams in conjunction with equations) with commentary, and looking up to face and talk to the class and interact with students. The lecturer asked questions of the students and also responded to student initiated questions, looking up as necessary.

Figure 1. Lecture theatre seating 172.

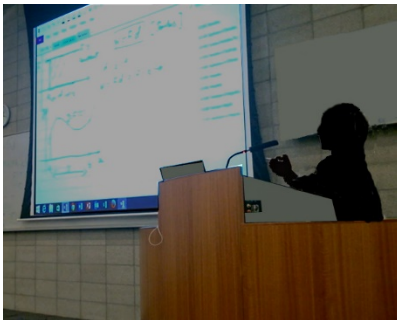


Figure 2. Lecturer raises head to gesture.

The majority of the session involved the exposition of theoretical concepts and example problems using both diagrammatic and symbolic representations written on the penTPC (and projected). The lecturer did not use any diagrams or figures other than those hand drawn, or any other software, in the observed session, and used a single coloured pen throughout. In terms of the content used and developed, there was nothing that was significantly different from what might have been developed on a whiteboard. On occasions the lecturer scrolled back to previous material, adding attentional marks (such as circling) to indicate relevant material (rather than deictic gestures toward DPSc content).

While talking to the class, the lecturer used hand gestures in a ‘traditional’ way i.e. gestures were made with the hands involving beat dimensions for emphasis, and iconic dimensions (e.g. moving one hand to and fro in association with saying ‘move object from one place to another place’).

In survey comments, the lecturer was very positive about the use of the penTPC, valuing the ability to remain at a desk, with a microphone, and to “not need to jump in front of the board”. The lecturer also valued the fact that the lecture notes were clear and visible to all students especially given the large class (and room) size. The lecturer also appreciated being always orientated facing the students and expressed the view that in using the penTPC “the teaching becomes more effective as students feel free and can participate in discussions”. The lecturer valued the fact that notes did not need to be erased to make space for new notes, and that notes could be made available to students after the class.

Case 2: Undergraduate (Yr 1) Engineering Mathematics Lecture (2)

This lecturer was in the second semester of using a penTPC, and also teaching a first year undergraduate engineering mathematics class. The environment was a medium size tiered lecture theatre, seating 236. Approximately 90 students were present. There was a large DPSc extending to approximately 3 metres above floor, with a strip of white board along the front of room, partially obscured when the DPSc was lowered.

The lecturer conducted the observed session using the penTPC and single DPSc as the only presentation technology. The Lecturer was confident and fluent in the use of the penTPC. Some material was handwritten live on the penTPC (within Microsoft OneNote), and other material was presented in the form of prepared static slides. The lecturer alternated between working at the lectern using the penTPC and walking away from the lectern, in front of the screen, to talk to the class.

While writing on the penTPC at the lectern the lecturer followed the pattern of dynamically developing both diagrammatic and symbolic representations in conjunction with dialogue, as a mathematical narrative. Rather than using a deictic gesture or mark to indicate location, location was associated with the position of appearance of specific content. For example, in referring to a region on a graph as "over here", the location of "here" was only made explicit for students by the appearance of the label being written at that place. Material was scrolled vertically so that new information was generally being added in the blank space immediately below previously written material.

There was occasional use of horizontal lines, short diagonal lines or boxes; rather than being attentional marks for emphasis, these marks served as separators, to distinguish one block of content from another (for example, between sample problems). Most of the material was written in the penTPC using black ink, with occasional use of a different colour to distinguish key points of interest (e.g. blue lines to highlight turning points on a hand drawn line graph).

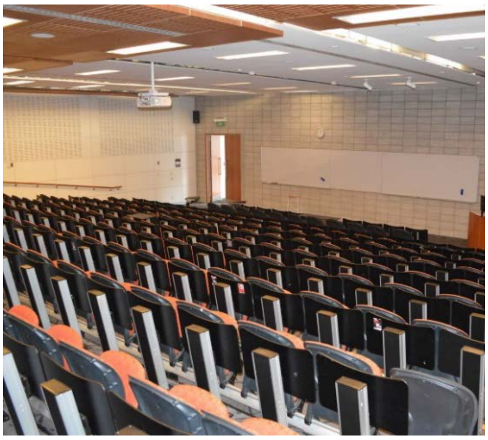


Figure 3: Lecture theatre seating 236.

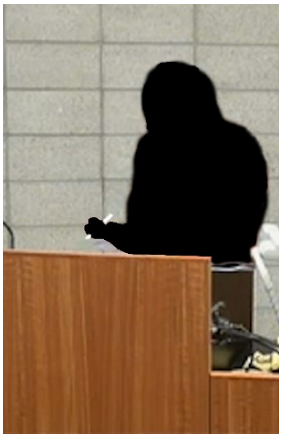


Figure 4: Lecturer writes on penTPC at lectern.

Figure 5: Lecturer gestures towards point of interest on DPSc.

The lecturer displayed slides using PDF reader software and did not annotate this material using the penTPC. When projecting slides, the lecturer would frequently move in front of the screen to discuss the material being presented, often pointing directly at material displayed on the screen while commenting (e.g. "going up and down"). In this lecture theatre only the bottom half of the DPSc is within reach, so while items of interest on the lower section of the screen were pointed at directly, with a hand placed contiguous to the screen material, items at the top of the screen were referenced by positional statements e.g. 'the first one', referring to a slide displaying three theorems. Other than these pointing (deictic) gestures, the lecturer was quite restrained in the use of hand gestures while standing.

In the lecturer survey, the lecturer rated the whiteboard as a preferred technology, but stated that the penTPC was almost always used for teaching and that it "works as well as a whiteboard". In describing advantages of the penTPC, it was described as "no better than a whiteboard, except that the notes are kept online and can be exported to PDF and other formats". Comment was made that white board space in many rooms was limited and "ineffective", and was obstructed once the DPSc was lowered, and these issues being a driver for using the penTPC. As in Case 1, the handwritten material observed being developed using the penTPC was not significantly different from what might have been developed on a board.

Case 3: Undergraduate (Yr 3) Engineering Design Lecture

This lecturer was in second semester of using a penTPC, teaching engineering design to third year undergraduate students. The teaching space was a large flat-floor classroom seating up to 60 (with 30 students present), with individual tables and chairs, set in rows. The room contained a lecturer desk at the front, side of the room, and a whiteboard that was partially obscured when the small DPSc was lowered (Figure 6).

The lecturer conducted the session solely with the penTPC using Microsoft OneNote, mostly sitting at a desk at the front, to the side of the DPSc facing the students. The lecturer moved naturally between sitting (while writing, annotating and talking) and standing and moving about the room (using a range of body movements and gestures). The lecturer would occasionally indicate towards the screen (deictic gesture) while sitting, but would often get up and move to the screen to point to a specific point of interest on the screen, or to talk to the students. The positioning and small size of the DPSc allowed pointing with a hand directly proximate to items of interest on the screen.

Figure 6. Flat-floor classroom seating 60.

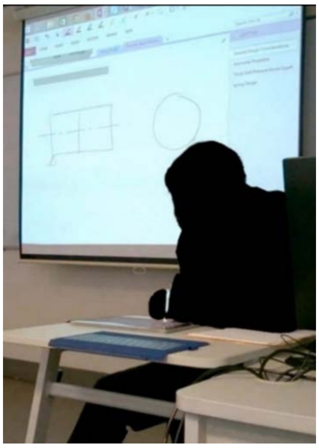
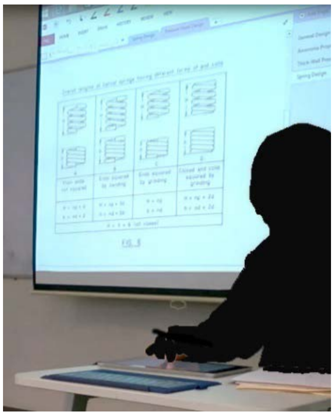
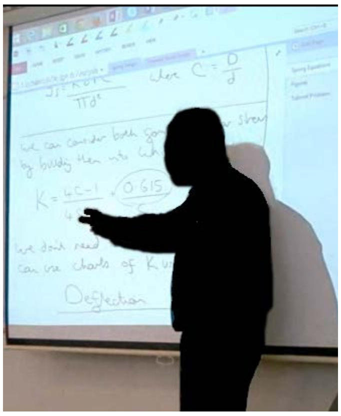


Figure 7. Lecturer writes on penTPC sitting at desk.

The lecturer (as in the previous cases) developed a mathematical narrative involving dynamic development of diagrammatic and symbolic material. However, this lecturer had incorporated prepared digital material on the OneNote pages, including engineering tables, standard formulae and diagrams, and referenced and added to this material during the session. For example, while referencing tables, the lecturer used attentional marks on the penTPC to indicate the relevant position in the table (drawing lines to indicate appropriate rows and circling relevant values) and on other occasions standing and pointing to the position on the DPSc. Underlining (often doubled) was used to emphasise important results. The lecturer used the zooming and scrolling capabilities of the hardware/software to focus on salient aspects of the content (such as zooming in on relevant sections of a table). The lecturer made the digital notes available to the students after the class, and in commencing the observed session, displayed and reviewed notes developed in the previous session. Thus in integrating other digital material, the lecturer was using capabilities of the penTPC that are not available in a board based environment.





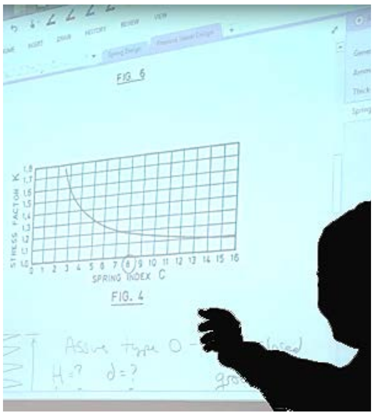


Figure 8. Lecturer references table of images within OneNote page.

Figure 9. Lecturer stands to point to specific location on projected image.

Figure 10. While seated Lecturer annotates graph on penTPC and also points towards DPSc.

In feedback, the lecturer commented that facing the students while drawing and talking was considered to be an important element of classroom presentation that was facilitated by the penTPC. The lecturer also valued the capability with the penTPC to project material at a large scale (via the DPSc), to integrate the handwritten OneNote material with other media, and to produce a record of the material as developed in class.

Case 4: Undergraduate (Yr 3) Engineering Statics

This lecturer was in the third semester of using a penTPC, teaching engineering mechanics to first year undergraduate students in a large tiered lecture theatre seating 360. Approximately 200 students were present. The lectern was at the front, centre of theatre. There were dual Data Projector Screens (and a larger single screen option). There were no wall-mounted whiteboards, but one small portable whiteboard was located to the side and beneath one DPSc.

Figure 11. Large lecture theatre seating 360.

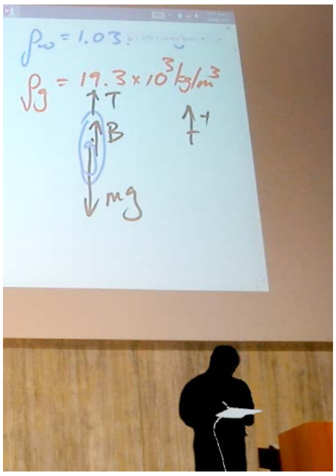


Figure 12. Lecturer stands to write, holding penTPC.

The lecturer conducted the session using the dual data projectors. One DPSc displayed PowerPoint slides (driven from the lectern PC) containing theory or textbook example questions, which were not annotated during the session. The other projector was used to display handwritten material created live on the penTPC using Microsoft OneNote. The lecturer would commonly walk to the side of the lectern while elaborating on slide material, and used hand/arm gestures freely. The lecturer used the penTPC to develop solutions to problems mostly standing with the penTPC resting on the lectern, and occasionally picking the penTPC up in one hand and moving to the side of the lectern (as enabled by the 2m cable) to write with the other hand.

Once again, the session proceeded as a mathematical narrative; the lecturer hand-wrote equations integrated with diagrams and verbal commentary. The lecturer would frequently look up to interact with the class, asking questions and clarifying points, and gesturing (beat and iconic gestures) with a hand (or hands, if not holding the penTPC). The lecturer used attentional marks (e.g. circling with highlighter ink, drawing a box around a result) to emphasise particular items, and linked associated objects with lines. The lecturer used a range of colours for emphasis and to distinguish different features. On occasion, colour was chosen with deliberate association to content (for example, switching to a blue pen and drawing wavy lines to indicate water in a diagram). Pen strokes were clear and of broad width, appropriate to the large venue.

The lecturer scrolled the (OneNote) pages to add additional functional material, and on occasion scrolled back to refer to previously developed material.

The features of penTPC use that lecturer valued were: facing the class; markers that didn't fade; the capability to use annotations and remove them; the capability to bring in images. The lecturer commented that the penTPC served as "a whiteboard on steroids". The lack of whiteboards in rooms was stated as being a key influence on adopting the penTPC approach.

Case 5: Undergraduate (Yr 2) Mathematics

This lecturer was in the first semester of using a penTPC, and teaching second year undergraduate engineering mathematics in a medium sized tiered lecture theatre (seating 236), with approximately 100 students present. A lectern was situated at the front, side of the theatre. There was a single DPSc and a strip of fixed whiteboard that was partially obscured when the screen was lowered.

Figure 13. Lecturer lifts head to talk and gesture while at lectern.

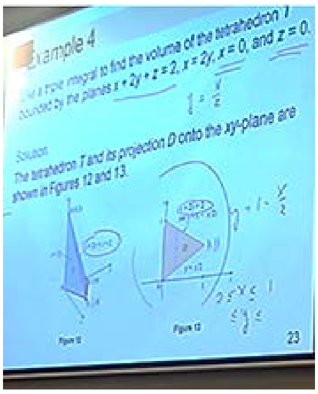


Figure 14. New material is added and attention is drawn to key material with annotations such as circling.

Figure 15. Lecturer moves to side to talk about material, and gesture.

The lecturer used PowerPoint, running off the penTPC, projected on the single DPSc. PowerPoint presentation slides had been prepared in two forms, with some containing extensive content and others allowing additional blank space for annotation and development of additional material.

When developing material, the lecturer used the penTPC on the (standing-height lectern), and spoke facing the students while writing. Problem solutions were developed as a sequential mathematical narrative, in an equivalent manner to that of a board environment. On occasion the lecturer would look up to talk, remaining at the lectern, and gesture. At times, previously written material was referred back to, and identified with attentional marks (circling).

Some PowerPoint presentation slides had extensive content, often including diagrams, some of which were complex representations of 3D figures that are hard to draw live by hand. These slides were annotated mainly using attentional marks (circling, underlines etc.) on the pre-written material to indicate points of particular focus, concurrent with speech (e.g. "this plane" while circling the appropriate surface-plane on figure on the penTPC). Some annotations added functional information (e.g. an additional line as a functional component of a diagram). When expanding on a topic or asking questions the lecturer would often move into the space between the lectern and screen to address the students while facing them, occasionally glancing and/or gesturing towards the screen.

Feedback from this lecturer included seeing the penTPC environment as having value in allowing the maintenance of a stance facing students while writing, and in facilitating the use of prepared slide material in conjunction with writing activity without the need to switch from whiteboard to DPSc.

Case 6: Undergraduate (Yr 3) Electrical Engineering

This lecturer was in their fifth semester of using a penTPC, teaching a 3rd year undergraduate paper in control engineering. The room used for the session was a medium size flat-floor classroom (seating 50) with a lecturer desk at the front to the side of the room. There was a single DPSc which partially obscured a whiteboard when lowered.

The lecturer conducted the session using the penTPC and Microsoft OneNote to display prepared material and add live handwritten material. The lecturer set up the penTPC on a desk at the front (to the side of the normal lecturer desk) and sat facing the class while writing/annotating in OneNote and displaying output on the DPSc. The lecturer had earlier inserted PowerPoint slides (originally developed in previous years) as printouts in a OneNote page, and this material was further developed in the session. Slides included photographs and software-created graphics. The lecturer used the touch capability of the penTPC to scroll through the material, and zoom in and out on elements of interest.

The lecturer took advantage of the capability of OneNote to provide an unconstrained writing area in scrolling to the right of the slide material to expand on the material presented in the slides. Different coloured inks were used with specific meaning assigned to different colours in some situations. This use of colour in the functional writing added emphasis that would not otherwise be as apparent.

Figure 16. PowerPoint slide printed into OneNote and then annotated live in the class session.

Figure 17. Lecturer gestures in circular motion ("cows walk around crater in contours").

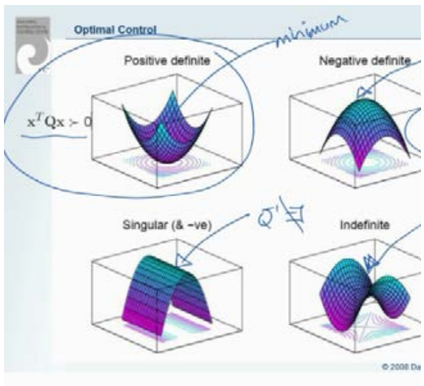


Figure 18. Lecturer annotates software output using penTPC.

The lecturer freely interspersed writing/annotating with looking up and gesturing (e.g. drawing circular contour lines on an image, and then making iconic circular hand gestures). Labels were added and linked to relevant points on a diagram with arrows. Thus many annotations served to add functional information, but also as attentional marks to add emphasis within the sequence of the narrative. From time to time the lecturer also would stand and move to the centre-front of the class to discuss material, freely using a range of gestures.

In questionnaire response and other comments, the lecturer had expressed valuing: sitting, facing the students; ability to use a range of representational forms and colour; using a handwritten approach allowed dynamic development of material, in ways that was less formal (than text), and maintained a student-friendly pace; capability to make completed notes available to students as both a static and dynamic recording.

Case 7: Undergraduate (Yr 3) Statistics

While this lecturer was no longer using a penTPC, having personally decided there were too many disadvantages with the technology, the session is included to provide a comparative analysis. The session was a 3rd year undergraduate statistics class in a "flexible blended learning space" (flat-floor classroom) seating 36, with approximately 25 students present. The room has a lectern at the left-front, a single DPSc connected to a lectern desktop PC, and two portable whiteboards placed to the right hand side of the DPSc. Room furniture consists of trapezoidal tables, arranged in groups seating up to 6, with chairs on castors.

The lecturer used the lectern PC to project use of statistical software (i.e. showing command inputs and text and graphical outputs) onto the DPSc. The two portable whiteboards were used to develop theory and examples. The lecturer was very active, moving between the lectern PC (to enter software commands), the DPSc (to point to output) and the whiteboards to develop theory and examples. The board writing was mostly with a single-colour of markers (with occasional use of a second colour, for emphasis), the lecturer writing with back to the class, talking towards the board. The lecturer's body frequently obscured material as it was being added. The lecturer frequently pointed to features of specific interest on hand-drawn diagrams, or used annotations to highlight existing features, or add new features, along with verbal commentary. There was ready transition between pointing to existing diagrammatic features, and switching to using the in-hand marker to add new features or emphasis.

Figure 19. Room with DPSc and portable whiteboard.

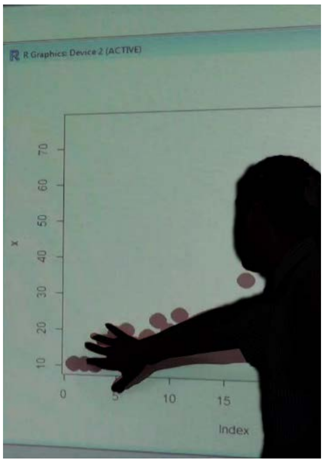


Figure 20. Lecturer points to item of interest on DPSc.

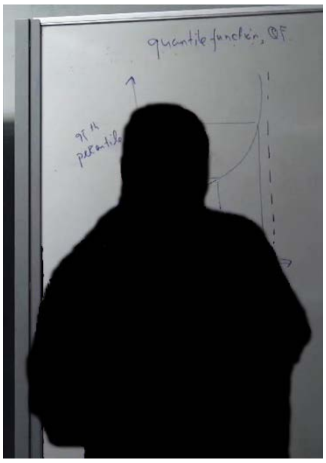


Figure 21. Lecturer writes, facing the board.

When referring to material on the DPSc the lecturer used whole arm movements to point or touch contiguous to the output of interest, but written annotations were not applied (as this capability was not available). On occasion some screen material was elaborated on by reproducing material on the board. Again, gaze (and voice) were mostly directed to the board/screen, and at times the images on the DPSc were partially obscured and or shadowed by the lecturer's body. The reasons given by the lecturer for abandoning use of the penTPC include: technical-reliability issues; regarding the technology as forming a barrier between lecturer and students, with the need to "have to look down" to use it; that the "text moves around, unlike writing on a board which stays put until erased."

Analysis and Comment

Characteristic elements of a mathematical lesson, as identified by Fox and Artemeva (2011) are shown in Table 1, with Column 1 showing the forms characteristic of the board classroom, and column 2 the equivalent (and additional) forms in the penTPC environment. The alphabetic code assigned to the rows in Table 1 (e.g. [A]) are used to identify these elements in the following discussion.

The basic process of developing a mathematical narrative, involving writing mathematical symbols, texts, graphs and diagrams [A] while verbalising [B], was observed to take similar form in both board and penTPC environments. In both environments lecturers would verbalise while they were writing [C], and stop writing to talk about what they had written [D]. However, there were differences in how they moved in space [E], and in the use of gestures [F].

While *in the process of writing* [A] lecturers using the penTPC were more static with regard to whole body positioning. Lecturers did not move across the room as a board user would as they wrote progressively across a board, but were "tied to the tablet" (Bonnington et al., 2007, p. 8). Nevertheless, the sessions examined here showed that lecturers could (and would, according to preference) move freely, stepping away from the device, when talking about what *had been written* [D]. In doing so the lecturer would interact with the displayed material as they would in with board-based material or slides displayed on a DPSc, potentially using a full range of gestures [F], but with limitations, as discussed below.

Table 1: Components of mathematical narrative in board-based and penTPC classes (after Fox and Artemeva (2011))

Element Code	Board classroom - co-occurring Elements	Tablet PC - Co-occurring Elements
A	writing mathematical symbolism and text **on a board**; drawing graphs/diagrams	writing mathematical symbolism and text **on the penTPC**; drawing graphs/diagrams
B	referring to problem sets and textbook chapters	referring to problem sets and textbook chapters
C	verbalizing what is being written while writing **on the board**	verbalizing what is being written while writing **on the penTPC**
D	talking about what has been **written on the board**	talking about what has been written **on the penTPC**
E	moving in space	moving in space (away from the penTPC, and with the penTPC)
F	gesturing (including pointing) to indicate relationships, signal references, highlight key issues, and so on	***annotating*** (and *where possible*, gesturing) to indicate relationships, signal references, highlight key issues, and so on
G	consulting/reading lecture notes,	consulting/reading lecture notes
H	**stepping back from the board**, pausing the action for reflection	**looking up from the penTPC**, pausing the action for reflection
I	checking student understanding by quickly glancing at the class	checking student understanding by quickly glancing at the class
J	**turning to students** and asking questions, and talking with students	**Looking up from the penTPC** and asking questions, and talking with students
K		Inclusion of detailed graphic images/diagrams in presented material for subsequent development and **annotation**
L		Use of graphic images or video for development of conceptual understanding
M		Dynamic use of software to produce tables, diagrams, visualisations; copy and paste into pages for subsequent annotation

In the penTPC environment, whole body movement was not necessary to transition between writing and other interactions; rather than stopping writing and turning (as with a board technology), the lecturers just stopped writing and looked up. Thus the activities of talking [D], some forms of gesturing [F], consulting of notes [G], pausing for reflection [H], checking student understanding [I] and asking questions [J] were possible without needing to turn or move away from the device (although that option was available). In board-based teaching, it has been noted that 75% of the lecturer's time might be spent with body facing the board (Fox & Artemeva, 2011, pp. 95–96). Most lecturers in this study saw it as a key advantage of the penTPC mode for their body to be facing the students (rather than the board) while writing and talking [A][C], allowing them to simply glance up to talk [D] and interact with students [I][J].

However, in Case 7 here the lecturer regarded the penTPC as a barrier in the relationship with students, seeing "looking down to write", as an activity that disrupted the normal flow of a lesson. As observed, the lecturer was very active in class, in both body movement and gesture. This style was also recorded by Bonnington et al (2007, p. 8), who noted a lecturer's observation that his "distinctive dramatic style involving much arm-waving and walking around to emphasise points" was severely constrained in the penTPC environment. It may be that for some lecturers, the penTPC requires too radical a change to their accustomed movements for it to be comfortably adopted.

A critical difference between board and penTPC environments is in the capability for use of deictic (pointing) gestures [F], while talking about what had been [D], or was in the process of being [A][C], written. While writing at a board, a lecturer can simply point to an object for emphasis (as well as circle or underline), but when working at a penTPC the lecturer needs either to use an attentional mark or to move away from the device to point to the object on the projected image [E][F]. Furthermore, depending on the size and positioning of the DPSc, lecturers were not always able to position a hand directly adjacent to the indicated object, so that pointing, or deictic gestures were less precise, or constrained, compared to a board environment. Thus in the penTPC environment, the use of annotation, in the form of attentional marks, becomes an essential mechanism for indicating relationships, signalling references and highlighting key issues [F].

For the lecturer working on the Tablet screen, the focal point of the writing operation is directly that of the tip of the stylus (as directed by the hand/arm), with touch actions also operating directly on the on-screen representation of objects, as if in direct physical contact. Thus while the lecturer maintains, in their sight, the linkage between their physical and mental focus, the student only explicitly views the results of lecturer actions (on the Tablet PC screen) in changes as projected on the DPSc, without the physical cues of arm/hand pointing to the location of activity. The student is thus very reliant on visual cues on the screen to focus attention on the point of interest, and the lecturer needs to give conscious attention to the creation of these cues. While developing symbolic content following a standard left-to-right, top-to-bottom sequence, the position of new material was generally able to be readily anticipated, and was clearly apparent. However, for material not entered in such a sequence (for example, when a lecturer added a label to an existing chart, or new point on an existing graph) it was important that this added material had sufficient prominence, through use of colour and/or size and dynamic development, to ensure the location of the point (the “here” in the verbal commentary) was immediately obvious.

As described by Bunt et al. (2009, p. 229) (as referenced earlier) the development of a mathematical narrative involves the simultaneous development of dynamic objects with writing occurring in sequence with verbal commentary. As observed here (in Case 1), commentary stating "from point *a* to point *b*" was accompanied with the marking, and labelling, of these points on a previously drawn graph axis. Subsequently the distance between these points was also identified, with a double-headed arrow joining the points and a new label added. Thus the timely addition of these points provides what we will term sequential emphasis; however, this writing also provides functional information that remains relevant after the commentary moves on, and even in a static form as written notes. There were only a few instances of use of purely attentional marks: at times underlines were used when referring back to previously written material, to emphasise words or terms that were again significant in the procedural flow; on one occasion a circle was used to highlight a symbol in an equation written earlier (requiring scrolling the screen to reveal, circle, and scrolling back to continue the narrative). In addition, some lines/points on a diagram were redrawn over with multiple strokes, to emphasise their location as relevant to the ongoing narrative. However, in most cases, it was the direct initial appearance of new content that gave emphasis to its sequence in the narrative.

As noted the penTPC environment provides capabilities to include a range of different graphic material in digital form directly into the writing and viewing space [K]. Not all lecturers made use of this affordance, with some simply using the penTPC as a basic writing slate, while others inserted additional material into presentations, closely integrating it into the mathematical narrative. For example, in Case 6, rather than rely purely on iconic gestures with the hands to suggest a volcanic crater, with circular motions to suggest contour lines within it (Fig. 17), the lecturer included a photograph of a crater, and drew contour lines directly on the image (Fig. 16). Graphic output from software (showing mathematic representations of craters) was also annotated, with both attentional and functional purpose (Fig. 15). Similarly, in Case 5, the lecturer displayed a full table of values, and annotated (circled or highlighted) relevant values for the ongoing calculations. Thus these annotations had both short term attentional purpose, as well as long term functional purpose in providing a permanent record of the origin of values that were used later in procedural developments.

In this study, annotations such as arrows were observed being used to dynamically connect equivalent items in the different representational forms (images, tables, diagrams, symbolic forms), and in enabling different representational forms to be integrated (such as dynamically adding symbolic equations to diagrams). While some use of annotation in this way may be observed in the board environment, the extended range of representational forms [K][L][M] available in the digital penTPC environment provides additional opportunities for annotation, and unlike transient gestures and speech, was observed here serving a contextual, attentional purpose, while adding persistent functional information. That annotation may be used for emphasis (attentional marks) and to communicate functional content has been noted previously (Alibali et al., 2014; Ambikairajah, Epps, Sheng, & Celler, 2007). Thus, rather than regarding annotations as being of distinct types, it may be appropriate to regard them also as having a range of dimensions, following McNeill's approach to types of gesture (McNeill, 2005, p. 38). An initial suggestion for categorising dimensional forms of annotations is shown as Table 2.

Classroom sessions in mathematical disciplines have traditionally been structured around having large areas of board space remaining visible and displaying unchanged content during at least part of a session (but erased at some point). The use of penTPC software means all content is retained (even after a session), but a smaller proportion may remain in the field of view displayed by the DPSc at any one time, and other material requires scrolling or zooming to access. Zooming and panning was used as an additional mechanism for providing emphasis, by centring and enlarging critical information on the DPSc. From the perspective of the lecturer, this mechanism has some characteristics of gesture, in that a hand movement initiates a communication, with direct results of that action manifest in the display. However, the hand action is not directly visible to the students, who only observe the resulting change in display. As such, these (and zooming/panning) might arguably be termed as *technology-mediated deictic gestures* (Table 3).

When using a mouse, the position of attention is indicated on-screen by a mouse *pointer icon*. This pointer icon can also be activated in the penTPC environment by hovering the pen over the screen. Thus rather than creating persistent attentional marks, focus can be directed to particular locations by the lecturer, by their positioning, or pointing, with a pen or mouse. While the position of a standard mouse pointer may not always be obvious on a DPSC, there are techniques and settings to increase its visibility (for example, increasing the cursor/pointer size, using the CTRL key to reveal mouse/pen position, or using the laser pointer tool in PowerPoint). In addition, the pen-as-pointer tool in OneNote can be used to make a transient annotation (a mark that disappears after a short interval). These actions have features of a technology mediated gesture, but may be better classified as transient annotations, in the trace register (Table 3). While the use of specialised pointer icons was not observed in this study, it is an issue for further investigation.

Table 2: Forms of annotation, distinguished by suggested dimensions/purpose

Annotation Dimension	Description/Purpose	Examples
attentional focus (simple mark)	Directs attention to point in written narrative	Dot or indistinct mark
conceptual emphasis (emblem)	Focus or re-focus on key objects (equations, terms)	Box, highlight
sequential emphasis (emblem)	Call attentions to an existing object at critically relevant time in the narrative	Circled item “this”;
sequential emphasis (content)	Addition of content object at critically relevant time in the narrative	Addition of written content, point ‘a’, or tangent on curve
closure/completion (emblem)	Indicates completion of a task, or separates coherent sections	Double diagonal lines // horizontal line - ____________
Linking (emblem)	Connects different objects, or the same object in different representations	Arrows, lines connecting value, symbol in an expression or calculation with value in a table
associative or cohesive (emblem)	Collects objects having a common property together	Enclosing objects within line; use of common colour for ‘like’ items
Iconic representational (pantomime)	Representational drawing or graphic	Wheeled cart drawn in mechanics problem
iconic association - metaphoric form (pantomime)	Format of object reflects a property of object	Spring drawn as zigzag lines Use of blue colour, wavy lines to represent water on a diagram
Structured functional content	Diagram, graph, algebraic working, text (or part of)	Equation, mathematical working

Note that anotations may have more than one purpose. As with gestures, there may be an associated progression of formality, from simple marks (equivalent to gesticulations), through conventional signs (emblems), iconic or representational content (pantomime), through to functional content structured according to formal rules (sign language).

The affordance of the penTPC environment for ready use of colour in annotation has been previously noted (Fister & McCarthy, 2008; Wilson & Maclaren, 2013), although it has been observed elsewhere that it is not consistently used in a meaningful way (Anderson et al., 2004, p. 573). While most lecturers here tended to use a single colour, or occasionally a second colour for emphasis, some lecturers here used a range of colours systematically, with concurrent attentional and functional purposes. For example, systematic use of colour in circling, highlighting or writing objects gave not just transient attention to particular objects, but provided ongoing focus on the common functional properties of the like-coloured objects.

Wang and Chu (2013) proposed that even non-representational beat gestures help convey meaning. While annotations may take on some of the role of iconic and deictic gestures, the beat gesture is not so readily transferred into a written form (with multiple underline strokes perhaps being one option). However, the lecturers did not appear to be constrained in the use of hand created beat gestures, simply looking up from the penTPC and moving hands (sometimes while holding pen, or glasses) in beat gestures to provide emphasis when talking about material.

Table 3: Technology mediated gestures and transient annotations

Technology mediated gestures (deictic) Involve hand actions by the lecturer, with features of a deictic gesture from their perspective, but with only the effects of those actions viewable to students on the DPSc (and not the hand movements themselves).	
Lecturer Action	Effect on DPSc
Pinch touch gesture	Screen expands to give overview
Stretch touch gesture	Focus directed to detail of content
Finger scroll	Focus directed to previous content
Transient annotations (deictic) Mouse/pointer actions have features of an annotation, and involve use of a tool, but are transient and do not appear in a static digital record of a session.	
Lecturer Action	Effect on DPSc
Mouse or pen-hovered over (points to) specific content (or pen-as–laser setting used) - directs attention	Transient appearance/movement of mouse-pointer position
Pen-as-pointer setting to annotate - directs attention	Annotation appears, but disappears after a few seconds)

Conclusions and Further Developments

It had been suggested that the use of the penTPC may affect communication in the classroom by constraining the range of movements and gestures used by the lecturer.

However, the examination of the use of penTPCs here has revealed that, while some changes were observed in the sequencing and features of movements, a wide range of communication elements used by the board-based lecturer were still exhibited, with use of gestures remaining as a core component in lecturer presentations. Thus the core elements of 'chalk talk' as described by Fox and Artemeva (2011) were observed in use, albeit in modified form, by lecturers using the penTPC (Table 1, Rows [A]-[J]).

It is in the reduced use of deictic gesture and expanded use of annotation that the most significant changes accompanying the introduction of the penTPC environment were manifest. It is apparent that annotation may provide a powerful way of conveying meaning that extends beyond that available through simple gesture.

While this study has been focused on the use of gesture and annotation as used by the lecturer in the classroom, the penTPC also readily enables classroom generated notes to later be made available to students as a permanent record of the session. Most lecturers here regarded this capability to provide a permanent digital record of all material that could be scrolled and accessed within and outside class sessions as an advantage of the penTPC approach, and made active use of the capability. The persistent nature of annotations (as opposed to the non-recorded ephemeral nature of gestures) can have a significant impact (both positive and negative) on the future use of recorded notes. The nature of the annotations (and gestures) made in class may also impact on any notes that students make themselves. These aspects are outside the scope of this paper (but are discussed in Chapter 10).

While the adoption of the technology has not been without technical issues, the majority of lecturers who have piloted the use of the penTPC determined that the benefits outweighed the disadvantages. In some cases, while there was initial resistance fostered by a view that the technology was only required because of the absence of suitable whiteboards in classrooms, lecturers became appreciative of the potential benefits of the penTPC approach. Some lecturers may find the restrictions on their established natural movement and use of gesture a challenge. The successful use of a penTPC approach requires adoption of different techniques, and a willingness to do so depends on how the individual lecturer perceives and weighs the relative advantages and disadvantages.

Unlike the established form of chalk talk as described by Artemeva and Fox (Artemeva & Fox, 2011; Fox & Artemeva, 2011), the precise form of delivery of the mathematical narrative in the penTPC environment is still evolving. It is apparent that the augmented capability for annotation in conjunction with other digital representations in the penTPC environment can provide opportunities to enhance teaching, particularly of STEM based discipline subjects. However, this study observed a wide range in current levels of utilisation of these affordances. The increasing adoption of the penTPC in the study university gives importance to the establishment of guidelines for their effective use, which will be a focus of ongoing work.

References

See References section at end of Thesis.

CHAPTER 7 / DISCUSSION: THE INITIAL DESIGN CYCLE

Initial Implementation Cycle

The preceding chapters examined a number of different aspects of the introduction of penTPC technology within the university. In the initial implementation, the primary design initiative was for the use of the penTPC in the classroom, as an alternative to whiteboard or PowerPoint delivery, or use of a document camera.

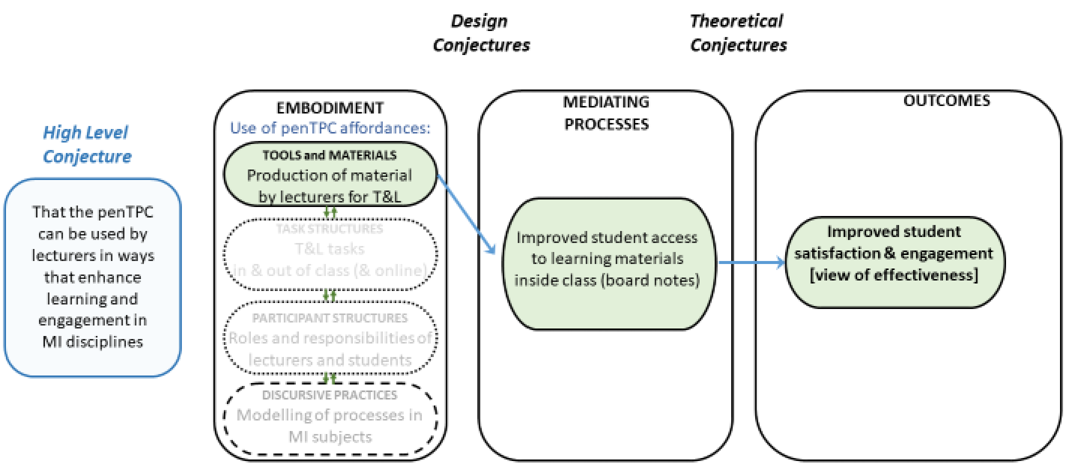


Figure 1. Conjecture map overview of penTPC project - initial phase.

In comparison to a whiteboard-based classroom delivery, the implementation mainly involved a change in the TOOLS AND MATERIALS component of the design. In the most basic usage, the penTPC was essentially just used in an augmentation role, replacing the board technology, but augmenting it through improved visibility and readability of the material produced, and not primarily through a change in content. Students (ARTICLE 2: I SEE WHAT YOU ARE DOING) preferred an approach that:

- displayed material in a format that is clearly visible, with legible writing, throughout the class environment (can see clearly), (can read handwriting)

While this might be considered obvious, it does reveal the limitations of whiteboards in many classroom situations; material written with markers on whiteboards is often too thin and too small to be easily read from any distance. In fact, much of the writing on whiteboards would not match recommended readability standards for signage.

TASK STRUCTURES, and PARTICIPANT STRUCTURES were essentially unchanged, with lecturers lecturing and students taking notes as in a traditional lecture. The DISCURSIVE PRACTICES WERE also mostly unchanged, apart from some aspects of the non-verbal communication, as described in ARTICLE 3: MAKING THE POINT. Some gestures (deictic) were constrained, as the material being displayed was not by default in a position to be pointed at with whole-arm movements. Full body movement was also more limited, with the lecturer more constrained to a location while writing, but able to look up to face the students (rather than write with back to the students on a board, and turn to face the students in a distinct change of pace. While some lecturers preferred the physically freer style of board writing, and a few being passionate about that preference, most of the lecturer participants appreciated the benefits of the penTPC delivery mode, and recognised their students' preferences for this mode.

In comparison to PowerPoint, the basic use of the penTPC might be seen as involving a more substantial change in DISCURSIVE PRACTICES, in moving back to a more traditional 'chalk talk' style approach. In a PowerPoint mode, relatively large chunks of already complete, formally structured material are presented on a slide all-at-once (rather than developed as a progression); the dialogue takes the form of a post-event commentary on what has been displayed. As reported in ARTICLE 2, students showed a strong preference for the traditional discursive approach in which explicit modelling of expert thinking style was carried out by the lecturer. Students preferred modes that:

- enabled the display of live, step-by-step development of theory and problem solution (doing/engaged).

Lecturer comments (as reported in ARTICLE 2) showed that the lecturers also placed importance on the explicit modelling of expert thinking as a key component of the teaching sessions, and valued handwriting capability as being an essential element of a delivery mode. Thus student and lecturer views were in agreement with conjectures expressed in the conceptual framework regarding the exposition of mathematical material.

However, in the case of MI disciplines, this disciplinary preference for expository-style handwritten approaches has been challenged by institutional imposition of digital environments that don't provide optimal support for handwriting. Lecture rooms have been built and equipped with digital technology, and with data projectors as the primary presentation mode. While document cameras are installed in some large rooms, their functionality is limited to the extent that they were rated by students as the least effective of the handwritten modes, and only slightly better than PowerPoint. In many rooms, use of PowerPoint is a form of delivery that is functionally advantaged, with data projection screens being placed with priority over whiteboards, encouraging the use of computer presentations. This has often meant the default use of PowerPoint even where it may not be educationally advisable. In this context, the use of the penTPC enables a return to the use of traditional DISCURSIVE PRACTICES.

Planning for Future Implementation Cycle

The introduction of the technology occurred in an environment that was not fully conducive to the implementation as a carefully structured and implemented DBR project. Institutional factors influenced the capability to implement multiple DBR cycles.

CHAPTER 8/ ARTICLE 4, following, analyses the institutional drivers and barriers that were encountered, and suggests factors that need to be accounted for in the planning for the implementation of a technology. It is seen as important that these issues be analysed as a key part of a DBR approach. The introduction of the technology in this research occurred as an emergent change, subject to factors that were not readily controlled. This constrained the scope of the design implementation and in DBR terms restricted the interventions to a single major cycle.

However, the DBR framework has been used to gain insights from the initial interventions that suggest potential directions for future developments. CHAPTER 9/ ARTICLE 5 examines student use of resources they currently use outside the classroom, and CHAPTER 10 examines student and staff views on notetaking in class. These lead to consideration of alternative approaches that would more substantive changes in delivery approach as potential developments for future design cycles, discussed in CHAPTER 11.

CHAPTER 8 / ARTICLE 4 - INSTITUTIONAL ADOPTION OF AN INNOVATIVE LEARNING AND TEACHING TECHNOLOGY: THE CASE OF THE PEN-ENABLED TABLET PC

Paper under Review.

Maclaren, P. (2017). Institutional adoption of an innovative learning and teaching technology: the case of the pen-enabled Tablet PC.

Submitted manuscript reformatted for this thesis.

Abstract

To be adopted by academics, a technology must first be made available within the university. However, the introduction of innovative learning and teaching technologies in a university context commonly occurs not as a planned change, but as an emergent change, driven by individuals acting as champions. As initiatives proceed, they will encounter conflicting organisational goals. Academic agendas for creative engagement may conflict with ICT agendas for system integrity, and organisational management structures may favour system-wide technologies over more innovative technologies with a localised focus. This study explores a case involving the introduction of pen-enabled Tablet PC technology. Institutional drivers and barriers are analysed to identify strategies that may support the adoption of innovative technologies.

Introduction

This paper explores factors influencing the introduction of educational technologies in universities, through a case involving pen-enabled Tablet PC (penTPC) technology. An educational technology is assumed to be one that is used for the enhancement of learning and teaching (L&T), regardless of its original design purpose. An innovation is considered as something new even if the newness is just within the local context (McKenzie, Alexander, Harper, & Anderson, 2005). Many studies have focused on the adoption of technology by individuals, using Rogers' (1983) adopter categories, in which an implicit assumption is that the technology choice is readily available to the individuals. However, as Rogers notes, in institutional contexts there may be constraints; "an individual cannot adopt a new idea until an organisation has previously adopted (it)" (p. 359). This paper examines the processes by which an innovative educational technology may become available within a university context so that it has the potential to attain widespread adoption.

Organisational-driven planned innovation has been described as progressing through a series of managed phases: initiation, implementation, and institutionalization or continuation, as shown in Figure 1 (Fullan, 2007; Kirschner, Hendricks, Paas, Wopereis, & Cordewener, 2004). However, innovation frequently emerges not in a planned way, but as an "emergent change" (Iles & Sutherland, 2001, p. 14), with a combination of internal organisational structures, cultures and goals, and external factors, "shaping the change process by 'drift' rather than by design" (p. 14). Individual champions may work to influence the direction of change and enlist resources (Cummings, Phillips, Tilbrook, & Lowe, 2005). In emergent change, phases are less distinct and less able to be planned and managed, and progress to subsequent phases is less certain than Figure 1 would suggest.

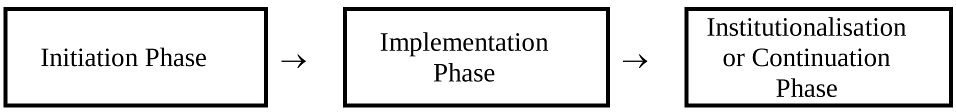


Figure 1. Phases of development in organisationally-driven technology innovation.

Organisational structures, cultures, and goals have been identified as strong factors influencing emergent change, so it is appropriate to examine their form in the university context. Universities are complex organizations that have been described as organized anarchies, comprised of a number of loosely coupled systems (Giesecke, 1991; Kallenberg, 2016; Kezar, 2001; Weick, 1976). Berger and Millen (2000) describe university functioning as characterised by "problematic goals, unclear technologies, fluid participation, and high levels of ambiguity and uncertainty" (p. 290), and the issues to be resolved have been characterised as wicked problems that lack deterministic solutions (Marshall, 2016; Rittel & Webber, 1973). A consequence is that many university decision making processes may follow a Garbage Can Model (Cohen, March, & Olsen, 1972; Fioretti & Lomi, 2008) in which outcomes are determined by a transient mix of decision makers, choice opportunities, potential solutions looking for problems, and problems looking for solutions.

Schein (1996) identified three organizational cultures in a traditional business: an operator culture, an engineering culture, and an executive culture. In a university context, academics are operators in the sense of servicing core functions of teaching and research, but are more autonomous than in typical businesses, with much of the decision making on course design and delivery devolved to individual academics or academic groups. Academics embody both the operator-delivery and engineering-design roles of a conventional business. Senior academics may also have an operational-administrative role, including positions on committees at a range of levels (from department to university-wide), some with governance functions. A singular viewpoint will not prevail across all academic groups, however, and significant differences in approaches may exist across different academic disciplines – to the extent that they have been described as ‘academic tribes’ (Trowler, Saunders, & Bamber, 2012). Institutional groups or committees may involve a changing mix of academics from these different tribes. While some administrative and logistic functions may be located within academic departments, the core functions of finance, estates, and ICT are typically centralised. Those sub-systems typically have management cultures that more closely match those of conventional business models and function using relatively tightly defined operational parameters and procedures, often constrained by externally defined requirements (Bleiklie & Kogan, 2007; Kallenberg, 2016; Kezar, 2001). Similarly, it has been suggested that the executive/governance role in universities has become more managerial, particularly with regard to financial control (Chong, Geare, & Willett, 2017; Larsen, Maassen, & Stensaker, 2009; Shattock, 2013).

Within a university context, the key functional systems, with designated roles and associated cultures, may thus be classified as:

- operational: the academic faculty, performing core operational functions (L&T, research), and including academic middle management functions;

- executive/governance: institutional strategy and management, meeting external requirements;

- administrative and logistical: providing support for functions that are not education-specific – such as Information and Communication Technology Services (ICT), finance, HR and marketing.

In addition, most institutions have education-specific academic advisory units that support academics in developing their operational capabilities in L&T, and research, but generally do not have a governance role.

The executive/governance system is responsible for presenting unified strategic plans that are intended to crystallise institutional goals and guide decision making. Sharrock (2012) analysed the goals of four Australian universities as expressed in strategic statements and identified four key priority zones, defined as Professional Community (PC), Creative Engagement (CE), System Integrity (SI), and Sustainable Enterprise (SE). Sharrock noted that these zones identified competing demands, contrasting seeking flexibility with maintaining stability, and looking inward with looking outward. These four zones aggregate a range of competing goal priorities, or polarities, identified by McNaught (2003). While strategic goals may be presented as part of a unified plan, the inherent polarity of these goals means that achieving them all simultaneously is problematic. Sharrock suggested "each zone implies a different focus and outlook, a different set of imperatives, and different styles of managing on the part of the leaders involved" (Sharrock, 2012, p. 330). Decision-making requires a negotiated balance between competing priorities and agendas, and outcomes at any time may depend on the mix of agents involved. Innovation is commonly regarded as essential within modern organisations, including universities (Dobni & Klassen, 2015; Tierney, 2014), and is expressed as a key element of the university CE agenda (Sharrock, 2012). However, innovation may conflict with goals focused on maintaining robust systems (SI) and supporting collegial values of staff (PC). The extent to which adoption of innovation is part of a strategic goal of being a sustainable enterprise (SE) may depend on the extent to which the university sees its traditional model as being challenged. The introduction of an innovation exposes the inherent tension between organisation structures and cultures that encourage new approaches and those that are focussed on sustaining established approaches (McNaught, 2003; Salmon, 2014). “Breaking the inertia of the status quo is seen as one of the top barriers to innovation” (Dobni & Klassen, 2015, p. 104).

Just as technology use has become more pervasive within administrative domains, it has also become an increasingly critical component in L&T. Many educational technology developments arise from academic interest in the pedagogic value of evolving commercial and research technologies, and the introduction of new technologies in a university environment commonly involves a range of institutional and external stakeholders, with differing organizational roles and cultures (Kezar, 2001). Kenny (2002) suggests that innovative projects require more open management processes to suit the way that academics traditionally work, to recognise informal networks and enable less structured approaches with processes that are not predictable and ordered. Giesecke (1991) suggests that flexibility in an organisation can involve “embracing the processes found in an organized anarchy” (p. 66), by suspending constraining regulations, encouraging playful experimentation, and establishing flexible work structures.

However, central administrative and logistical units, such as ICT and finance, emphasise systematic approaches with formal project management methods focussed on leveraging existing enterprise systems. With their primary focus on maintaining system integrity (Dent, 2015), ICT departments will often play a gatekeeper role on the adoption of technology, even in the L&T context (Wilmore, 2014). As the university has become more efficient in these business processes, it may also become less able to adopt more radical innovations (Weise & Christensen, 2014), particularly those that require changes in existing systems models or technical competencies of the actors in that system (Pisano, 2015). As well as innovations originating within the university, ICT units acting within a SI agenda and on restricted budgets may also face challenges accommodating rapid developments and innovations occurring within the IT industry. Thus initiatives involving innovative technology may encounter potentially conflicting agendas of academics and ICT professionals (Salmon & Angood, 2013), and universities face challenges in developing an approach that "balances academic aspirations and institutional resources" (Sharrock, 2012, p. 324).

This paper explores the example of an innovation project that evolved as an emergent change initiative. It provides a narrative that analyses the initiative in terms of the frameworks that describe phases of projects, organisational systems and cultures, conflicting organisational goals, and varying decision-making processes. While the specific case examined concerns the introduction of penTPC technology in a university environment the findings are generalised to provide potential insights in other technology adoption scenarios.

The case narrative

The organisational context

The organisational context of the study is represented in Figure 2, which shows the institutional units that have key relevance to this analysis. Internal (university) units are identified by their system function as either executive/governance, operational/academic, or administrative/logistical. The suppliers of computing hardware and software, and building design, are identified as key external units.

External context and conception of initiative

The external context and origins of this innovation project trace back to the initial commercial development of the Microsoft pen-enabled penTPC in 2002. The initial form of the penTPC technology was a high-powered convertible-laptop with a swivelling screen that supported touch and pen input. The technology suggested a strong educational potential, with a workshop involving a range of university researchers and industry developers suggesting:

> The Tablet PC has the potential to dramatically alter the educational process. This new technology significantly changes the way students and teachers interact. It adds completely new dimensions to classroom interaction by providing digital ink and drawing tools for writing, sketching, and drawing; and for real-time collaboration" (Alvarado et al., 2004, p. 1).

Continuing academic interest was reported in a series of annual conference/workshops beginning in 2006 (Berque, Prey, & Reed, 2006). Developments in Australia and the UK were also documented by Loch and Fisher (2010), with the Monash eEducation Centre running an Australasian Tablets in Education Conference in 2009 and 2010. Academic early adopters were attracted by applications of pen input within STEM disciplines, and by software development opportunities (Reed, Berque, & Konkle, 2009).

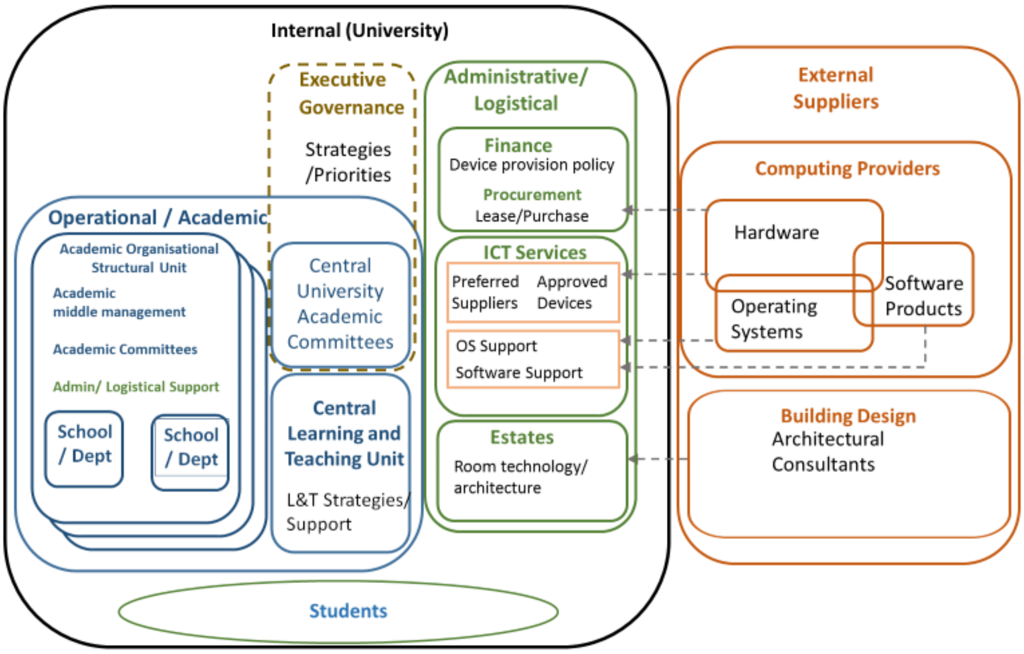


Figure 2. Organisational entities and their system functions.

The pedagogic rationale for adopting penTPC technology was to facilitate support for handwritten material in digital environments. In mathematically intensive (MI) classes the development of mathematical ideas in a dynamic, handwritten style has been established as a core element of teaching (Artemeva & Fox, 2011; Greiffenhagen, 2014). MI disciplines use multiple representational forms, including hand drawn diagrams and equations (Bunt, Terry, & Lank, 2009; Kober, 2015). The use of computing interfaces that support dynamically drawn and handwritten material enhances development of ideational fluency and inferential reasoning, particularly in STEM disciplines (Oviatt, 2013a). By extending computing capabilities to enable ready communication using hand drawn representations in digital environments, the penTPC offered potential to support innovative pedagogic approaches.

Despite the enthusiasm of early advocates, the penTPC failed to achieve widespread public adoption. The early technology was found to be technically and physically limiting, as too heavy and cumbersome for easy use, and with insufficient battery life (Bright, 2010; Spillers, 2009). For most consumers the inking capability was unnecessary and did not justify the additional cost over a standard laptop. Despite pockets of strong support in education and business (Anderson, Schwager, & Kerns, 2006), the penTPC remained a relatively niche product. In 2010 Apple introduced the iPad, and revolutionised expectations of what a tablet computer could be. A design based on a reduced set of capabilities (compared to a penTPC) led to a much-simplified device that excelled in basic communication and information display tasks. The device was an outstanding success in the consumer market (Bright, 2010) and there was immediate interest in exploring its educational applications (Manuguerra & Petocz, 2011; Murphy, 2011). However, as the original iPad, by design-intent, did not support precise pen input and lacked a full computer operating system (OS) it was not a replacement for those using the full functionality of the penTPC.

Manufacturers of Microsoft penTPCs responded with a range of different form factors utilising rapidly developing hardware and software. Some developments at this time pushed innovation at the expense of established standards and consumer expectations, and on occasion, rapid innovation came at the expense of reliability and stability. Windows 8, optimized for touchscreen (and pen-enabled) computers became generally available late in 2012, followed by Windows 8.1 in 2013. However, these versions of Windows were not well accepted, particularly by desktop users and in enterprise environments (Jansen, 2013). By 2013 several manufacturers, including Lenovo, Asus and Samsung, had introduced 2-in-1 penTPCs (tablet-style PCs with detachable keyboards). In 2013, Microsoft entered the penTPC hardware market directly with the Surface penTPC. Windows 10, made generally available in July 2015, was a move back to a more desktop-centric OS, while maintaining penTPC-friendly hybrid capabilities. In an educational setting, the penTPC continued to be of interest in MI disciplines because of its support for handwritten input in the form of digital ink. The rapid advance of technology allowed the production of penTPCs in form factors that approached the thinness, lightness and battery life of the iPad, reviving interest in the use of the device.

The university project

The penTPC project of this study was an emergent change initiative arising as a bottom-up CE development. An initial conceptual phase was influenced by earlier initiatives at other universities, where developments had been fostered by groups investigating the potential functionality for teaching within specific disciplines. An academic advisor acquired a penTPC device in 2008, and acted as advocate for the technology within STEM disciplines. Supported by a group of academics within a MI teaching department, funding for a pilot project was eventually obtained in 2012. A central university grant enabled the purchase of six penTPCs for academics in engineering to use in teaching, as a proof of concept. In terms of innovation, it was a use of existing (or evolving) technology that would be new in the local context (McKenzie et al., 2005). In terms of organisational goals, this project was supported by an institutional CE agenda through an innovation grant fund designated to support the introduction of new L&T initiatives. The allocation of grant funds to projects was a decision of executive/middle-management responsible for the central L&T support department. The project faced strong funding competition from other projects using differing technologies, with substantial institutional resourcing going into the supply of iPads to staff, and provision of support mechanisms for their use

(Frielick et al., 2013). While the penTPC was not a similarly favoured technology within the L&T centre, increasing emphasis institutionally and nationally on supporting development in STEM disciplines assisted in the project receiving some funding.

Institutional ICT policies required that any PC device connected to wired networks be approved and use a standard university OS image. Before penTPC devices could be acquired for the project, a change occurred in the approved institutional hardware provider. Delays occurred until suitable devices were identified and approved, acquired, and an approved institutional OS image installed. This image was designed for desktop PCs - devices with an established, conventional hardware and that remained in one place for use by multiple users. In contrast, the penTPC was a device that embodied a rapidly evolving technology, designed to be used by a single user in multiple places. Using the standard desktop image meant that some device-specific programs, interfaces and system components were not necessarily loaded or updated, resulting in some features of the penTPC, particularly those related to the specialised pen digitizer and touch screen features, being inconsistently implemented. Many desktop ICT policies made little sense on a tablet-style individual-user device with touchscreens and detachable keyboards. Rapid external development in Windows versions resulted in ongoing problems maintaining a suitable institutional OS. The standard university desktop image remained as XP until moving to Windows 7 in 2012. However, Windows 8 (and later, 8.1) was necessary to enable the core functionality of newer penTPC devices introduced from 2012. It took some time and considerable energy from project champions to negotiate a suitable, practical implementation of the university OS for these devices. In the initial stages of the pilot project close support was provided by an ICT technician who met regularly with the project participants and addressed technical issues as they were raised.

However, this support was soon reassigned by ICT management to other ICT priority areas. Resolution of technical issues with the penTPC implementation were consistently identified by ICT management as having a lower priority than desktop PC issues, given the relatively small number of penTPCs. Many ICT service staff had limited knowledge of penTPCs, and support was reliant on the project champion and some individual ICT staff informed through their personal interest in the devices, rather than official channels.

At one point the ICT department acknowledged the difficulties of supporting innovation within existing procedures, and suggested seeking funding through an ICT managed funding process. A grant was sought to establish support systems for penTPCs that would operate independently of the constraints and priorities of existing systems. Competing grant applications covered a wide range of ICT projects, including standard infrastructure development and maintenance projects. After an extensive process, the grants committee (made up of a range of ICT and Faculty representatives) allocated some funding, but there was no alteration within ICT made to departmental resourcing for this project. Implementation of the penTPC technology remained constrained by an ICT agenda that continued to prioritise existing systems.

Despite the technical issues, the pilot project generated a mostly positive response from the students and staff involved. Ironically, the development of new teaching spaces within the university helped foster the acceptance of the technology; the capabilities of the penTPC enabled continuing use of traditional handwriting modes vital to the chalk-talk style lecture approach, compensating for the absence of suitable whiteboard facilities in these new spaces (Maclaren, Wilson, & Klymchuk, 2017a). This support enabled progress to an extended implementation phase. Key individuals at a faculty governance level provided special grant funding for additional penTPC devices. Once again, problems were encountered with device acquisition, with the ICT approved PC manufacturer unable to supply a device with the necessary capabilities. It took several months before ICT would approve a replacement device from an alternative supplier, only for it to be removed from the approved list a few months later. It was not until the introduction of the MS Surface Pro 3 in late 2014 that stability in device availability was achieved, with the device meeting both ICT department and project requirements. These difficulties reflected a conflict between the conservative SI agenda of the ICT department and the strong innovation agenda being pursued by external suppliers of both hardware and software at the time. While Microsoft's new CEO has stated that their industry "only respects innovation" (Nadella, 2014) it is apparent that institutional ICT service providers may be challenged by rapid and substantive industry changes; an external industry focus on innovation can be resisted by a conservative customer base (Nobel, 2012).

While access to hardware was obviously critical, application software that supported hand written input was also essential. A range of pen-enabled software platforms had been developed alongside the early introduction of the penTPC, with a number of universities taking a key role (Alvarado et al., 2004; Anderson et al., 2004; Berque et al., 2006; Tront, 2007; Wilkerson, Griswold, & Simon, 2005). Later MeTL was developed by the Monash eEducation Centre (Bailey, Hagan, Hagan, Franke, & Sanson, 2011). These different software options were investigated for use for the study, but supporting ICT resourcing was not readily available. By the time funding was approved for the trial penTPC project, Microsoft's OneNote package had acquired at least nominal support within the university as part of the MS Office Suite, and provided sufficient functionality to make it a viable option.

In terms of changes to L&T approaches, the adoption of the penTPC did enable augmentation of the standard pedagogic approach, with some lecturers recording screencasts and lecture notes and making this material available online. However, the device was primarily used to sustain existing lecture-based signature pedagogies (Shulman, 2005b). While collegial agendas (PC) may be accepting of individuals voluntarily trialing new technologies, they may be inherently more conservative in resisting substantive changes in embedded teaching practices. As observed elsewhere, despite the enthusiastic development of new spatial environments guided by higher-level processes operating under an institutional CE/SE agenda, there has not been widespread adoption of different teaching approaches in new spaces (de la Harpe, Fraser, Mason, & Hurford, 2014; Steel & Andrews, 2012). Other factors, including timetabling based on university-wide classroom allocation (an SI/SE agenda) and maintenance of traditional learning outcomes and assessment schedules (an SI agenda), have continued to implicitly favour a traditional lecture-based approach.

At the current time the project has reached a critical stage where it might potentially transition from an extended implementation phase to a longer term institutionally-supported implementation. In many respects, this has resulted from penTPC technology maturing, and being more widely promoted, to the extent that it has entered mainstream acceptance and is mostly manageable within standard ICT support systems. Windows 10, implemented in the university in 2017, suits penTPCs as well as desktops without requiring substantial customisation. The penTPC hardware format has stabilised and penTPC are now being adopted more widely within both academic and administrative departments. Some ICT challenges remain, such as managing firmware updates that are not routinely pushed out to these devices. OneNote is a component of an institutional

Office 365 installation, but support channels for its use as a standard learning technology tool are not yet established. While a designated group within the L&T centre provides user support for the LMS and other standard university learning technologies, the development in use of OneNote as an additional L&T tool has largely occurred independently of this group. While a capability to enroll students in a OneNote Class Notebook through integration with the LMS has been established, it required intervention by the project champion, rather than resulting from standard institutional processes. Similarly, while linking assignment marking in OneNote with the LMS gradebook would have high value in the project terms, it remains a low-priority option in institutional system terms. The development of the use of penTPC technology as a component of pedagogical change within this university is still dependent on initiatives of individual champions.

Analysis and Discussion

The penTPC project discussed here is an example of an emergent change, that arose outside the context of a centralised, organisationally-driven project. Different phases were subject to varying influences that either hindered or supported development, and outcomes of each phase were not predictable. This is a common experience in such projects; as Ewell (2002, p. 11) noted, "successful change initiatives in higher education settings must rely on persuasion, diffusion, and voluntary adoption far more than on top-down implementation". Adaptive responses were necessary in different phases to negotiate a path through differing organisational strategies and agendas. Rather than the carefully planned sequential phases of Figure 1, a more complex model of phases of technology adoption is suggested in Figure 3. At any stage, a project may backtrack or end (formally or informally).

A first phase of an emergent innovation project involves conceptual formulation, often with the perception of an opportunity, rather than recognition of an existing need. Rogers (1983, p. 360) notes that a "high level of knowledge and expertise" within an organisation can facilitate the initiation of innovations. The academic culture of the university provides an environment that is generally conducive to the development of new ideas under a CE agenda. Statements from the strategic documents of the study university show a strong emphasis on CE, epitomised in the institutional branding as "the university for the changing world" (AUT, 2017). The academic environment also supports the sharing of new ideas through conferences and workshops (PC agenda), and these have both informed and subsequently promulgated the developments here.

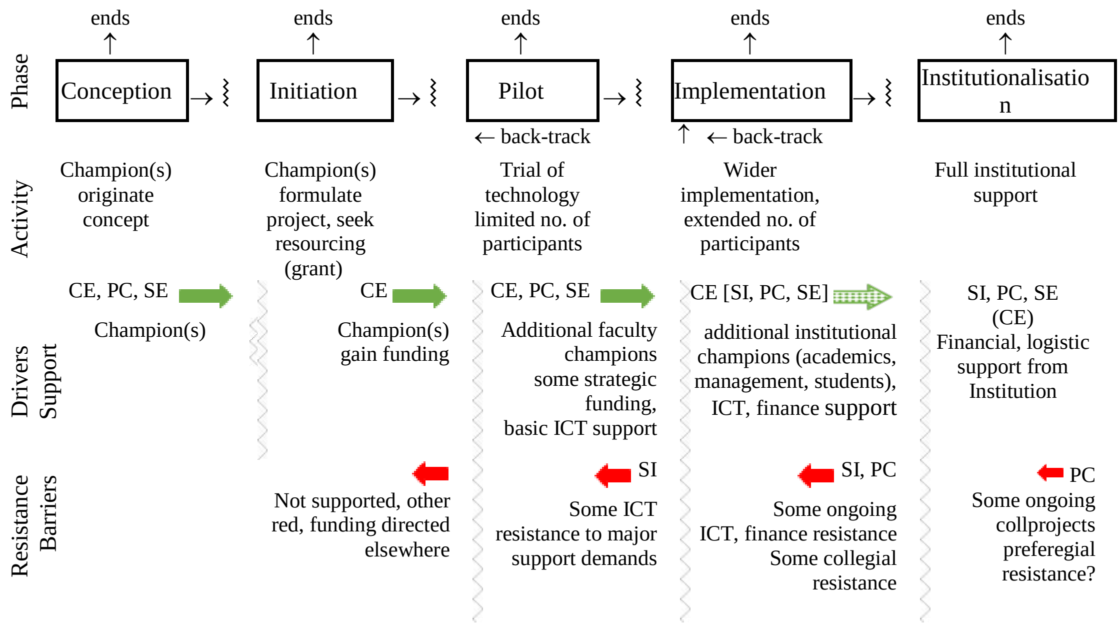


Figure 3. Phases of development in an emergent innovation project (example).

Key: CE = Creative Engagement; PC = Professional Community; SI = System Integrity; SE = Sustainable Enterprise;. ⦚ indicates potential barrier.

An initiation phase involves the formulation of a pilot project, with identification of the resources that are necessary to progress to a practical implementation, and potential sources of those resources. Many universities fund learning technology projects through grants, which are generally contestable, and frequently externally funded (Ewell, 2002; Jackson, 2013). Decision-making processes by which grants are allocated may have features of the garbage can model described earlier, in that outcomes are dependent on a changing mix of institutional representatives, contesting problems, and solutions (Cohen et al., 1972). The organisational structure underlying the grant allocation process can have significant impact on which projects proceed, in determining the make-up of decision-making bodies; the personal and professional viewpoints, and sometimes tribal attitudes towards technology vendor products, of those involved in the process may have a strong influence on outcomes.

In a pilot phase, participation by academics is generally voluntary, and so the collegial agenda will not be significantly challenged. Funding for pilot projects is typically for a limited scale intervention, without any commitment of an ongoing operational budget. Access to continued funding is dependent on at least perceptions of success; it may be difficult to obtain clear quantitative metrics from a limited pilot. Support from academics and students involved, and importantly, an absence of active opposition from those not involved, is crucial. Indeed, at this stage if there has not been some growth in adoption, or at least maintenance of use, by individuals it may be that the technology does not have the attributes to justify continued use. Good logistical support is essential at a pilot stage, to resolve problems that may deter individuals from involvement. While some support may be acquired from ICT in the context of standard user support, if more substantial support is required there may be conflict with a primary SI agenda. SI goals tend to be less obviously promoted in public documents as they are generally not inspirational. While they may remain implicit, they can be powerfully embedded within administrative and logistical system management culture. The intervention of project champions may be necessary to enable effective support.

Even if a pilot phase is judged as successful, ongoing implementation is not guaranteed. To receive further funding, projects need to move from being regarded as an experimental innovation within a CE agenda, to being seen as addressing core functions within an SE agenda. In the case of the penTPC project, key academic and administrative staff at a faculty level regarded the technology as meeting a critical need for innovation in MI disciplines within the faculty, and championed further development; being in positions with influence over a faculty strategic budget, they were able to enable additional grants. However ongoing project-oriented resource funding is vulnerable to changes in management and tightened budgets; as Schein noted, the “field of organisation development is replete with examples of innovative new programs that did not survive executive succession” (Schein, 1996, p. 17). The eEducation Centre and MeTL software development at Monash did not survive a restructuring, and within the university in this study, the programme supporting staff in the use of iPads has not received ongoing funding. In contrast, the Virginia Tech School of Engineering has had consistent leadership in the use of the penTPC in its T&L approaches, to the extent that the purchase of a penTPC by students has been a requirement since 2006 (Thomas, 2016; Tront, 2007).

For an innovation to have longevity, it needs institutional policies that ensure ongoing high-level support. The innovation needs to become accepted as a core element of an SE agenda, with established ICT logistic support (SI). Where funding decisions are made at a centralised executive/governance level influenced from a strong managerial culture, it may be more difficult to obtain support for technologies that are not seen as having generic application across the whole institution. University ICT departments tend to focus on centralized systems, and make decisions on technology based on fit with existing systems, and using established industry decision-making processes (Cohen et al., 1972; Fioretti & Lomi, 2008). At the same time, substantive pedagogic change may be resisted by conservative agendas of teaching staff (PC) who face increasing pressures on other aspects of their role. Thus, there may be a systemic bias in high-level decision-making processes to favour centralised technologies that support relatively conservative approaches, rather than supporting a range of more localized innovative developments that may challenge existing pedagogic practices. For example, as a response to students’ poor experiences of lecture-based course delivery, a university might find it easier to use a top-down process to implement a centralised lecture capture system managed through

ICT channels, rather than to introduce alternatives to the use of lectures that involve more individualized technologies and varying pedagogic approaches.

Technologies that are less dependent on centralized, institutional support can have some initial implementation advantages. Introduction of the iPad, which did not support, and thus require, wired connectivity and multiple user logins, was not constrained by the related institutional standards. However, this independence also meant users were reliant on other sources for support, such as in finding appropriate apps to use in teaching environments. Despite initial enthusiasm, longer term institutional initiatives to promote iPad use have been constrained by a lack of clear guidance on “how best to align and integrate it within the academic programmes and workflows, and how best to manage it as a resource within a university’s organisational setting” (Nguyen, Barton, & Nguyen, 2015, p. 190). Similarly, while approaches based around the use of externally provided and maintained social software may avoid the necessity of conforming to ICT services agendas and allow more innovative approaches, the absence of integrated ICT support can also create longer term issues, such as lack of control over material and reliability of ongoing access (Schroeder, Minocha, & Schneider, 2010).

In this study, the penTPC project received initial support from academics and students in respect of its affordance for maintaining elements of a traditional signature pedagogy, while augmenting that pedagogy through the provision of online records of lectures and supplementary screencasts. The ongoing maintenance of the project in its current form, and development of more innovative uses of the device, are still constrained by current central finance department policies that limit an academic to a single lease computer; academics who require high-level desktop computing capabilities for some aspects of their work may be restricted in lacking access to the affordances, including portability, provided by a penTPC. While the technology might be used to support more innovative pedagogical approaches, implementation of such approaches is likely dependent on the emergence of a cohesive organisational strategy, with strong project champions across a range of leadership levels, particularly from within the academic community.

Conclusions

General Conclusions

The importance of carrying out systematic evaluation of projects throughout their successive phases has long been stressed in educational contexts, with various methodologies proposed (Bain, 1999; McKenzie et al., 2005). However, particularly in the case of emergent change initiatives, it is often institutional factors that determine whether innovations proceed to an institutional implementation phase, regardless of whether or not they are deemed successful. While universities may provide fertile ground for initiating emergent innovative projects, the focus and processes of decision-making at higher levels, and conflicts with an SI focused ICT agenda, may act to restrict their ongoing implementation (Bess & Dee, 2014; Jackson, 2013; McKenzie et al., 2005). As Rogers (1983), noted:

> each of the organisational structure variables is related to innovation in one direction during initiation, and in the opposite direction during implementation. Low centralization, high complexity, and low formalization facilitate initiation in the innovation process, but these same structural characteristics make it difficult for an organization to implement an innovation. (p. 361)

Christensen (2006, p. 41) made a distinction between sustaining innovations, that involve better ways of delivering what is already being done, and disruptive innovations that provide an alternative that eventually replaces the existing market. Sustaining innovations may often be associated with planned innovations, and can be readily evaluated to determine if they do in fact represent an improvement. However, disruptive innovations are more difficult to evaluate, as they may be oriented to needs that are not yet well defined or institutionally supported. Furthermore, they are "often sub-optimal in their early phases" (Assink, 2006, p. 225), and may initially "seem to be inferior to current practices" (Cosier & Hughes, 2001, p. 11). If evaluation is done too early, and is "too stringent we end up with too little innovation" (Dobni & Klassen, 2015, p. 114).

Christensen and Eyring (2011, p. 4) noted that "historically, higher education has avoided competitive disruption", and conservative use of technologies and traditional pedagogic approaches have prevailed. However, this status quo may not remain sustainable, even with incremental improvements (Tierney & Lanford, 2016; Weise & Christensen, 2014). In New Zealand industry groups have suggested that traditional degree provisions are no longer a fundamental requirement for employment (NZ Talent, 2017), and a government commission has suggested that "stability has come before innovation and the interests of students" (New Zealand Productivity Commission, 2017, p. iii). While some suggestions might ignore other wider purposes of a university education, they nevertheless raise concerns about the changing expectations of a wide range of university stakeholders.

Recommendations and implications

If universities wish to prepare for potential challenges offered by changing environments, they may need to modify their organisational strategy and structures, so that they are supportive of innovative developments beyond their initial inception stages. Existing SI, SE and PC agendas need to be examined as to their potential effect as barriers, and strategies established to either modify or work around these barriers. In particular, the university needs:

- To have a "well-articulated innovation strategy" (Dobni & Klassen, 2015, p. 116) that embeds an institutional commitment to foster innovation, and resource that innovation, through all phases, from conception to implementation. The SE agenda needs to explicitly support innovative change that addresses potential disruptions to existing practices, and not just the sustaining of existing practices.

- To address the resistance and barriers that arise from conservative SI agendas, particularly within administrative and logistical support systems. This might require the establishment of alternative organisational sub-units that are tasked with and importantly funded for incubating innovations independently of the core operational units with their focus on the SI of existing operations (Cosier & Hughes, 2001).

- To establish an environment that supports academics in the development and introduction of innovative pedagogic approaches, rather than reinforces traditional activities – involving a change in the PC agenda. While not suppressing experimentation, the university needs to ensure that the pedagogic rationale for implementing a technology is clearly articulated.

Implementing this strategy has implications for budgets; it must ensure that even in times of financial constraint, pedagogic applications of innovative learning technologies are investigated and supported. There needs to be recognition that "the intangible cost of not acting to meet future needs must be considered as well as the tangible cost of proceeding" (Howard & Guile, 1992, p. 47).

Limitations and opportunities for further research

This research has drawn primarily on experiences with one particular case of implementing a specific technology in one university. References in the literature suggest that this experience is not unique; readers will determine to what extent the recommendations have application in their own setting. Further research in this area may assist in developing and documenting approaches that achieve a balance between enabling freedom to innovate with meeting financial constraints and accountability requirements.

References

See References section at end of Thesis.

CHAPTER 9 / ARTICLE 5 - HOW IS THAT DONE? STUDENT VIEWS ON RESOURCES USED OUTSIDE THE ENGINEERING CLASSROOM

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Abstract

While the traditional lecture remains a key feature in the teaching of mathematically intensive disciplines at a tertiary level, what students do outside class, the resources they use, and how they use them, are critical factors in their success. This study reports on a survey of students studying a range of engineering subjects, giving their views on the effectiveness of resources that they use outside the classroom. Resource types examined included textbooks, lecturer course notes, in-class developed notes, and other online material, including multimedia. While lecturer generated material was generally seen as more effective than formal textbooks and social media, external screencasts were rated as most effective where material appropriate to their class was available. It is suggested that student use of screencast resources has the potential to facilitate improved learning outcomes, and with accompanying changes in assessment focus, may enable more substantive pedagogical changes.

Introduction

Traditional tertiary teaching approaches have a lecturer presenting new material using a board or other presentation technology and the students taking notes. For many years these elements have remained a fundamental component of a university experience for both lecturers and students, particularly in mathematically intensive disciplines (Carrier, Williams, & Dalgaard, 1988; Rensaa, 2014; Titsworth & Kiewra, 2004). However, in this traditional model, how time outside class is spent and the resources used are predominantly at the student's discretion, without direct intervention by lecturers (Maclaren, Wilson, & Klymchuk, 2017a).

This paper reports on student views of the effectiveness of different resources they use outside the classroom, including social media, prescribed textbooks, lecturer-developed coursebooks, lecturer class notes and digital material, and other external online resources, including multimedia. The students surveyed were studying engineering in a tertiary context, and in classes in which the lecturer was using a pen-enabled Tablet PC (penTPC), primarily as a whiteboard substitute in the classroom to project material as it was developed.

There has been ongoing interest in academic contexts in the use of social media, and Facebook in particular. It is suggested that social interactions are important in learners' construction of their own knowledge and that, for the current generation of students, online social media is a core medium for these interactions (Smith, 2016). Some research has suggested that Facebook is regarded primarily as a communication tool for talking about social and organisational aspects of the educational environment, rather than for problem-directed activities, and that it could be a distraction in a study context (Arteaga Sánchez, Cortijo, & Javed, 2014; Grosseck, Bran, & Tiru, 2011; Madge, Meek, Wellens, & Hooley, 2009; Smith 2016). The extent of use of social media by academics has been linked to discipline (Manca & Ranieri, 2016), with lower uptake observed in mathematical disciplines.

Textbooks are traditionally a core resource prescribed in most university courses. The textbook may be regarded as the authoritative source in defining what should be taught and assessed within an academic discipline area (Glasnović Gracin, 2014; Yerushalmy, 2015). How well a textbook matches the syllabus can be a primary criterion for their selection by lecturers (Dale, 2010). However, Rensaa (2014) found that students regarded lecture notes to be their most important learning resource. Hegeman (2015) also noted that resources generated by the instructor, rather than a commercial publisher were seen as better aligned with student needs.

Lecturer-generated materials may take the form of printed hardcopy materials or online resources. Lecturer material is commonly synthesised from a range of sources and provides a personal perspective on material that may not be available in a single textbook (Mulryan-Kyne, 2010, 179). The term coursebook, as used here, describes lecturer-generated material in the form of a printed textbook. A coursebook differs from a standard commercial textbook in that it is generally produced within the teaching department, in an inexpensive format (A4 spiral bound, black and white), and with material specific and limited to the particular course.

Three forms of lecturer-generated static notes, commonly made available online, were included in this study. The first, termed 'lecturer online notes', refers to digital materials, generally typeset, prepared before class and made available online through the Learning Management System (LMS). PowerPoint slides (typically in PDF format) are distinguished as a second separate form. It is a common practice to enable students to download these before class sessions to annotate in class (Babb & Ross, 2009). Thirdly, lecture 'handwritten session notes' refers to material developed during class and subsequently (or simultaneously) made accessible online as static notes (typically either as PDFs or in OneNote shared notebooks).

Handwritten lecture session notes are a readily accessible artefact of the penTPC environment. The apparent informality of handwritten notes can assist students to bridge the gap between formal textbook versions of solutions and their own work (Love & Pimm, 1996, 400–401). Previous research has suggested that providing lecturer generated notes for review out of class can aid student performance (Kiewra, 1985). However, as Schleppegrell (2007) observes, static notes, even when handwritten, lack the oral language of the lecture that helps the student negotiate complex material, and develop their mathematical thinking. While written notes from a lecture may be more accessible than content in textbooks and coursebooks, they are still missing the dynamic development of material and audio commentary of the live lecture.

A second multimedia form consists of dynamic recordings of a lecturer presentation on a computer screen along with audio. These are commonly termed a screencast. A range of studies have identified the potential benefits of screencasts for student learning (Francis, 2013; Loch et al., 2014). Guerrero, Baumgartel, and Zobott (2013) suggest screencasts may be more effective than textbooks or notes, in allowing students to watch videos at their own pace and rewind and review as required. When developed in a penTPC environment, the recorded screencast presentation typically includes live handwritten material. Previous studies have identified a preference for a handwritten format over typecast material, as being more “authentic” (Harrison, Pidcock, & Ward, 2009, p. 167). Screencasts may be made of a complete lecture session (Yoon and Sneddon 2011), or of short segments of material. While lecturer generated screencasts were not a standard resource at the time of the survey, some students will have had experience of them.

Finally, a range of online video or screencast resources are available on both general media sharing sites, such as YouTube, and through specialised educationally oriented sites such as the Khan Academy (http://www.khanacademy.org). The shorter form of Khan-style tutorial screencasts has been suggested to be more engaging and encourage more interaction outside class than videos of full lectures (Guo, Kim, & Rubin, 2014).

An ongoing concern in mathematics and engineering education is the balance between developing conceptual understanding and procedural fluency (Hiebert & Lefevre, 1986; Rittle-Johnson, Schneider, & Star, 2015; Star, 2005; Engelbrecht, Bergsten, & Kågesten, 2017; Crooks & Alibali, 2014; Pegg & Tall, 2010; Baroody, Feil, & Johnson, 2007; Schunn & Silk, 2011; Surif, Ibrahim, & Mokhtar, 2012; Kuo, Hull, Gupta, & Elby, 2013). There has been criticism that sites such as the Khan Academy focus on procedural techniques with a "do this, then do this approach" (Ani, 2013, p. 25), that creates an "illusion of understanding" (Schwartz, 2013, p. 1) – or in Skemp's terms (1976), encouraging instrumental understanding rather than relational understanding. A focus on procedural understanding has been observed in similar classes elsewhere (Tallman, Carlson, Bressoud, & Pearson, 2016). For students, previous examination and test papers can become the de facto authoritative source defining the material to be studied (Tobias & Raphael, 1996, 312). Thus the nature of assessments is a factor that may be expected to influence student views on resource effectiveness.

Research Significance

A number of previous studies, as discussed above, have concentrated on student responses to individual resource types and frequently include coverage over a range of non-specific disciplines. Rather than examining a single resource type in isolation, this study examines student perceptions of the comparative effectiveness of a range of different resources, as used outside class, and with a specific focus on mathematically intensive engineering classes. These classes are located in a STEM disciplinary context in which "visual, spatial, and mathematical representations are essential tools for communicating and remembering ideas and solving problems" (Kober, 2015, p. 77). This study includes consideration of issues associated with use of these representational forms. The study also includes an inspection of the nature of the assessments, with particular regard to the relative balance between procedural and conceptual understanding, and potential influence that these may have on student evaluations of the different resource types.

This study was conducted within a university located in Australasia that offers internationally accredited degrees in engineering and engineering technology. A predominant teaching approach in these disciplines is currently that of the traditional lecture based format, common across mathematical disciplines in many countries (Artemeva & Fox, 2011; Shulman, 2005b, 53–54). This research is purposefully focussed on examining the views of current students on what they regard as effective, given their current learning activities and assessment expectations. While student views of effectiveness may differ from those of other stakeholders, understanding student views is a research issue that has importance for educators in determining educational strategies (Nguyen et al., 2017). In examining aspects of learning related to procedural and conceptual development the research may be of relevance to any institution that currently follows similar traditional teaching approaches and to those having an interest in increasing adoption of research-based instructional strategies (National Research Council, 2012). The study will also inform a broader project that is investigating how penTPC technology might be used to support teaching and learning within STEM disciplines.

Study approach

The primary data source for this study is a 2015 survey covering five different subjects within an engineering context, involving class sessions conducted by six different lecturers. Institutional ethics approval was obtained for this survey. The selected sessions represented a convenience sample, based on timetabling and lecturer availability, covering a range of levels, from first year to 3rd year undergraduate level, including basic engineering mathematics (BEM) and more advanced and applied engineering (AAE) subjects. At the conclusion of the selected sessions, students were invited by the independent researcher to complete an optional anonymous paper-based survey, with the 480 survey returns representing over 95% of the students present.

Results from an initial analysis suggested that students studying BEM subjects had differing views from AAE students on the effectiveness of some resources. Thus results were evaluated separately within these subgroups, and differences between these BEM and AAE subgroups were also evaluated.

Students were asked to rate the effectiveness of, and comment on, nine categories of resource: social media (such as Facebook); commercial published textbooks; coursebooks; PowerPoint slides; lecturer-developed online course notes; post-lecture handwritten notes; lecture capture videos; screencasts; and external online resources. A mixed methods approach was used, involving non-parametric quantitative analysis of ratings, linked with a six-phase qualitative thematic analysis of comments as described by Braun and Clarke (2006).

Students rated resource effectiveness on a 5 point Likert-style scale, from very poor/very ineffective (coded -2), poor/ineffective (-1), average (0), good/effective (+1), through to very good/very effective (+2). These student resource ratings are shown for BEM and AAE subgroups, and overall in Table 1.

The practical importance of the differences in effectiveness ratings were quantified in terms of effect size (Coe, 2002). Success rate difference (SRD), expressed as a percentage (SRD%) was used as a suitable measure for expressing effect size (Maclaren, Wilson, & Klymchuk, 2017a). Calculation of SRD% involves two component percentages: the percentage of students who rate resource A better than resource B, minus the percentage who rate resource B better than resource A. Thus SRD% describes the perceived net benefit (or success) of one resource compared to another, with a value of 0% indicating no overall difference, and an absolute value of 100% indicating a resource is rated higher by all respondents. When comparing differing evaluations of the same resource type by the different (BEM and AAE) subgroups (Table 2), the SRD% expresses the effect size of the difference between the subgroups in their ratings. The two component percentages involved in calculating SRD% are also given in Tables 2, 3a, and 3b, as the second row in each cell. Estimates of the 95% confidence interval for SRD% are also calculated and are displayed in the relevant tables (third row in cells); where the confidence interval spans zero it indicates that the difference is not statistically significant.

There were wide variations in the resources available to students across the different class subjects surveyed. For example, not all courses had a prescribed textbook, or coursebook, and screencasts and videos were not standard resources in most classes. While students were encouraged to report based on their range of experiences across different classes and previous years, the current year of study and class subject may be expected to be a primary influence on ratings. A preliminary study of student comments suggested that student views of resource effectiveness were strongly influenced by their expectations of what would be assessed. Thus the results include an overview of the key features of the typical forms of assessment in the surveyed classes.

Results

Student Views of Effectiveness of Out-of-Class Resources

Student ratings of each resource, summarised as counts and percentages, are shown in Table 1, for subgroups (BEM and AAE) as well as overall. Subgroups results are displayed in a comparative stacked percentage column chart in Figure 1. To aid visual comparisons between resources and emphasise the nature of differences the position of bars in the chart in Figure 1 are adjusted to centre the average effectiveness categories on a common vertical datum line. Thus the portion of each bar to the right of the datum represents the proportion of students giving the resource an above average (or positive rating) plus half of those assigning an average rating.

Table 1. Ratings of effectiveness by resource, BEM, AAE and overall

		-2 very poor/ v ineffect %	-1 poor/ ineffect %	0 average %	1 good/ effective %	2 very good/ v effect %	Question Respondents n	%
Social Media	BEM	20	26	29	11	14	143	58
	AAE	13	25	37	15	9	149	63
	Total	16	25	33	13	12	292	61
Text book	BEM	5	20	29	29	18	204	83
	AAE	8	18	29	38	7	223	95
	Total	7	19	29	33	12	427	89
Course Book	BEM	3	12	31	37	18	235	96
	AAE	3	7	30	40	19	209	89
	Total	3	10	30	39	19	444	93
Power Point	BEM	4	8	30	37	21	225	92
	AAE	3	2	27	43	25	220	94
	Total	3	5	29	40	23	445	93
Lecturer Notes	BEM	1	8	24	40	27	234	96
	AAE	1	3	22	48	26	227	97
	Total	1	5	23	44	27	461	96
HandW Notes	BEM	5	8	22	35	31	214	87
	AAE	1	7	17	31	44	211	90
	Total	3	7	19	33	38	425	89
Video	BEM	9	8	17	34	33	175	71
	AAE	5	14	13	29	40	189	80
	Total	7	11	15	31	37	364	76
Screen Casts	BEM	5	10	24	32	29	165	67
	AAE	4	12	20	34	29	183	78
	Total	4	11	22	33	29	348	73
External Resource	BEM	2	7	12	34	44	203	83
	AAE	5	13	31	25	25	184	78
	Total	4	10	21	30	35	387	81

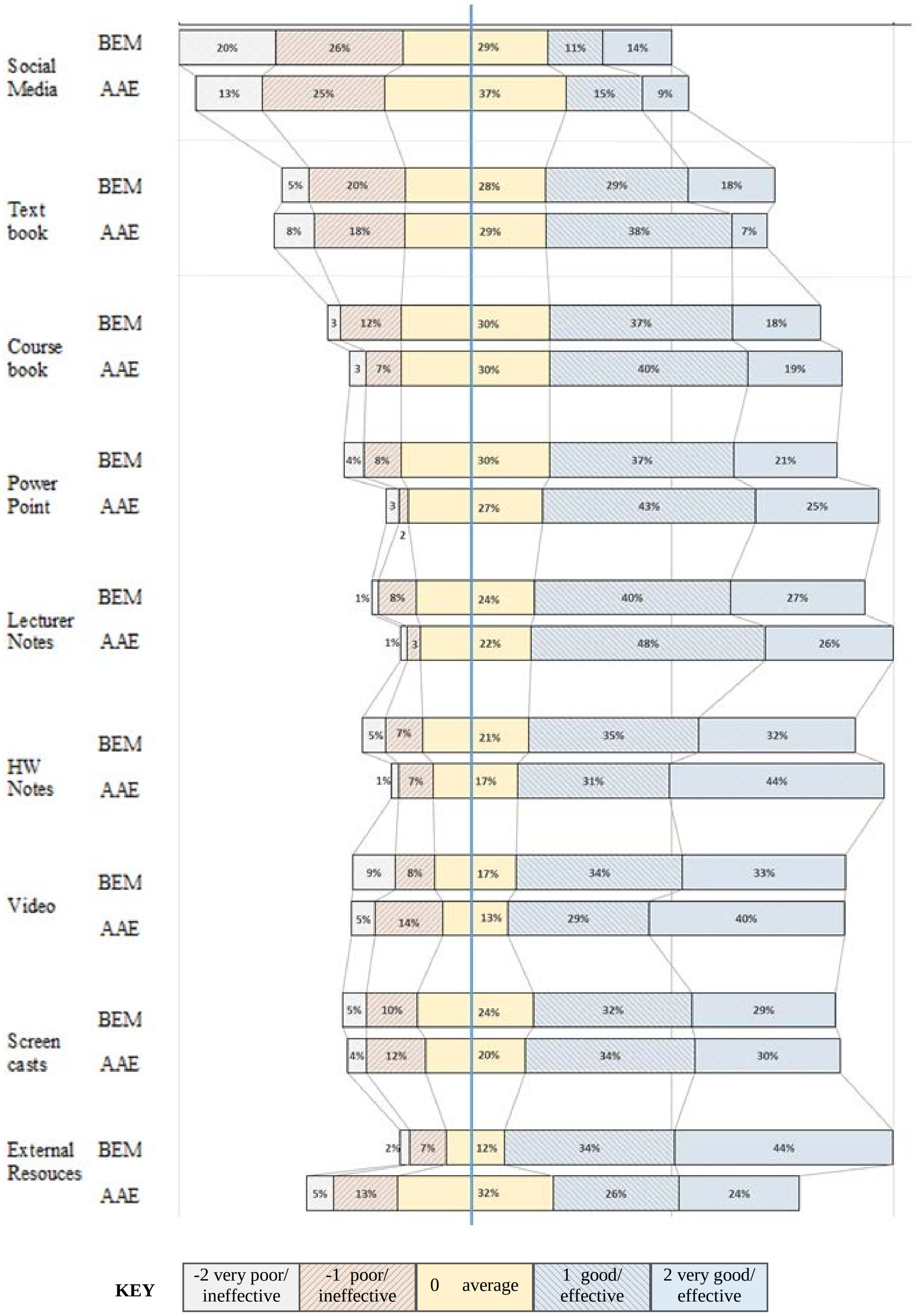

Figure 1. Student Ratings of Resource Effectiveness – BEM and AAE Classes. Values are percentages (rounded). Bar horizontal positions are adjusted to align the midpoints of the 'average' rating category.

Table 2 examines the effect size of the differences between BEM and AAE classes for each resource category, using SRD% as a measure. Further analysis involved comparison of resource ratings within BEM classes (displayed in Table 3a) within AAE classes (in Table 3b). A summary of the thematic analysis of comments is displayed in Table 4, and the most frequently referenced external sites are summarised in Table 5.

Table 2. Resource rating differences between BEM and AAE classes

Effect size as success rate difference (SRD%) moving from BEM to AAE classes. SRD% records the probability that an AAE student will rate the particular resource higher than a BEM student, minus the reverse (as a percentage); table line 2 records these component percentages; CI 95% (line 3) gives a 95% confidence interval for the SRD% and accompanying indication of significance (ns = nonsignificant).

		Print		Lecturer-generated static			Multimedia resources		
	Social Media	Text-book	Course book	Power-Point	Lecturer Notes	HW Notes	Video	Screen-casts	External Res
SRD%	5	-7	5	**12**	5	**14**	5	2	**-31**
Component percentages	(41-36)	(34-41)	(39-33)	**(41-29)**	(37-32)	**(43-29)**	(39-34)	(38-36)	**(22-53)**
CI 95%	-7 18 ns	-17 3 ns	-5 16 ns	**2 22**	5 15 ns	**3 24**	-6 16 ns	-10 13 ns	**-20 -41**

Effect size shading key	|SRD%| < 10% **S** Small effect	10% ≤ |SRD%| < 25% **MS** medium-small	25%≤|SRD%|< 50% **ML** medium-large	|SRD%|≥ 50% **L** Large

Table 3. Resource comparison effect size: BEM Classes - SRD%

Positive values indicate column resource is rated higher than row resource

	Text-book	Course book	Power-Point	Lecture Notes	HW Notes	Video	Screen-casts	External Res	Cell Contents Key
Social Media	30 (53-23) 15 43	35 (55-20) 21 47	45 (56-11) 33 56	57 (65-8) 46 67	50 (64-14) 37 61	45 (62-17) 30 57	45 (61-17) 30 57	55 (64-9) 43 65	SRD% Component% 95% CI
Text book		13 (35-22) 2 23	19 (41-22) 8 30	33 (49-17) 22 43	28 (50-21) 16 39	23 (48-25) 10 36	20 (43-24) 7 32	35 (53-18) 22 46	ns = not significant
Course book			6 (32-26) -4 17 ns	21 (41-20) 11 31	17 (40-23) 6 27	12 (40-28) -1 24 ns	13 (39-26) 0 25	33 (52-18) 22 44	Shading |SRD%|
Power Point				17 (26-9) 9 24	10 (33-22) 0 20	11 (39-28) -2 23 ns	6 (36-29) -6 19 ns	26 (47-21) 14 37	< 10% Small
Lecture Notes					0 (27-26) -9 10 ns	*-3* *(29-33)* *-15 9 ns*	*-6* *(26-32)* *-17 6 ns*	13 (36-23) 2 23	≥10, <25 medium-small
HW Notes						*-5* *(25-30)* *-16 7* ns	*-4* *(21-26)* *-15 6* ns	16 (36-20) 6 27	≥25, <50 medium-large
Video							*-4* *(25 -29)* *-16 8* ns	18 (39-21) 5 29	≥50 large
Screen casts								19 (39-19) 7 31	

Table 4. Resource comparison effect size: AAE Classes - SRD%

Positive values indicate column resource is rated higher than row resource

	Text-book	Course book	Power-Point	Lecture Notes	HandW Notes	Video	Screen-casts	External Resources	Cell Contents Key
Social Media	19 (43-24) 1 36	53 (64-11) 32 69	55 (64-8) 36 70	62 (70-8) 44 76	50 (63-12) 29 67	62 (72-10) 45 75	50 (64-14) 31 66	40 (54-13) 22 56	SRD% Component% % 95% CI
Text book		25 (45-20) 9 40	36 (51-15) 20 49	48 (33-61) 22 43	49 (64-15) 33 62	37 (57-21) 19 52	34 (57-22) 16 50	14 (41-28) 5 31	ns = not significant
Course book			14 (37-22) -1 29 ns	23 (40-17) 9 36	26 (46-20) 12 39	13 (40-27) 5 29	3 (35-32) -14 20 ns	*-12* *(28-40)* *-29 6 ns*	Shading |SRD%|
Power Point				8 (23-15) -4 20 ns	15 (36-21) 1 28	3 (32-29) -13 19 ns	*-7* *(28-35)* *-23 10*	*-17* *(39-22)* *-31 -2*	< 10% Small
Lecture Notes					11 (35-23) -3 25 ns	0 (31-31) -15 15 ns	*-14* *(24-38)* *-28 1 ns*	*-25* *(19-45)* *-39 -10*	≥10, <25 medium-small
HW Notes						-15 (20-35) -29 0	*-22* *(14-35)* *-35 -7*	*-32* *(17-49)* *-45 -17*	≥25, <50 medium-large
Video							*-8* *(23-31)* *-23 7 ns*	*-22* *(24-46)* *-39 -4*	≥50 large
Screen casts								*-19* *(22-41)* *-35 -2*	

Note. Component% (cell line 2) records the component percentages of SRD%. 95% CI gives the confidence interval for the SRD%, and where this interval spans zero, indicates the SRD% is not statistically significant (ns). Negative values (italic) indicate that the row resource was rated higher than the column resource.

Table 5. Thematic Analysis of Comments: Major themes by resource

Resource	Students making comments n % (of all)	Comments by sentiment (% of comments) +ve %	-ve %	Key themes, as identified by (#) respondents				
Social Media	35 7%	15 43%	17 49%	Good for group work (12), Ask friends (4)	distracts (3)		not used (3)	
Text book	64 13%	25 39%	38 59%	essential (2), good for extra examples (9), good for extra details (6)	too much info/ too complex (12)	not relevant/ not enough steps (3)	(mostly) not used (5) not purchased (2)	too expensive (11) heavy (1), prefer online (3)
Course book	54 12%	22 41%	26 48%	essential (3), has necessary info (4)	shows what to study (3)	hard to understand (7)	hard to manage/ bulky (4)	
Power Point	27 6%	15 56%	8 30%	good for reference (12)	don’t use (4)			
Lecture Notes	36 8%	15 42%	5 14%	good explanations (3)	shows what is required (3)	depends on lecturer (8)	don’t use (4)	
HW Notes	36 8%	27 75%	7 19%	good summary/reca p (13)	want OneNote in all classes (14)			
Video	64 13%	46 77%		like/want for all classes (46)	want short screencast(3)	too long (3)	need better quality (4)	
Screen casts	15 3%	11 67%	-	like (4)	would like (6)			
External Res	140 36%	126 90%	2 1%	List 1 or more sites (114)	Shows steps, pacing (8)		Can be confusing (1)	

Table 6. External Resources: Specific sites with most mentions in comments

Resource	Total number of responses	Khan Academy n	%	YouTube n	%	Patrick JMT n	%	Wolfram Alpha n	%	MIT n	%
BEM	245	38	15.5%	26	10.6%	10	4.1%	7	2.9%	1	0.4%
AAE	235	34	14.5%	26	11.1%	5	2.1%	3	1.3%	6	2.6%
All classes	480	72	15.0%	52	10.8%	15	3.1%	10	2.1%	7	1.5%

Note: Some respondents mention more than one site.

A detailed discussion of these results follows, along with student comments and context critical to their interpretation. Note that where student comments are included they are quoted verbatim, without grammatical correction.

Discussion

Social Media

As evident in Figure 1, social media was regarded as the least effective of the resources surveyed (overall 25% positive, 41% negative), significantly lower than all other resources (Table 3, 4). There was no significant difference between the subgroups BEM and AAE (Table 2) in their rating of social media. This was also the resource with the highest proportion of respondents indicating no opinion or offering no response (39%). Out of 35 comments, twelve were positive about collaboration benefits, with four specifically referencing use by friend-based groups, rather than class-wide structures ("good to ask mates"). Four comments indicated that social media was not used, at least in relation to the class. Three comments referred to the potential for distraction, with the comment "Pandora's box, good for information sharing but can be distracting" echoing the findings of Smith (2016), that social media may be a double edged sword.

Within the surveyed classes lecturers did not actively promote the use of social media as a component of class instruction, and its use does not appear to have been strongly pursued by students independently. The limited support for handwritten entry of complex mathematical material in common social media platforms has been identified as a potential barrier to online collaboration in mathematical disciplines (Lo et al., 2013), and may be a factor here. As noted earlier, free-hand writing and sketching are an important element in communicating mathematical ideas. To achieve a better "task-technology match" (Cao, Ajjan, & Hong, 2013) it may be appropriate to foster use of platforms such as OneNote, that support collaborative use of a range of forms of representation including freehand writing and drawing.

Published (Printed) Materials - the Textbook and Coursebook

Textbooks

Textbooks were regarded by both class subgroups as less effective than all other resources apart from Social Media (Figure 1, Table 3, 4), with the difference between AAE and BEM subgroups not statistically significant (Table 2). Some students made positive comments about the value of a textbook:

> wouldn't be passing without it, essential; textbooks with lots of practice questions are good; great for extra interest info

However, many comments questioned the value of having a prescribed textbook at all:

> have not purchased a textbook, got enough content to study; too much information that's not required; expensive & not using; only used when all else fails to help

These comments and the relatively low rating of the textbook reinforce the finding by Schmidt, Wagener, Smeets, Keemink, and van der Molen (2015), that a wider knowledge of the domain as covered in textbooks may be regarded as unnecessary by students. Previous research has suggested that where students do use a textbook, they focus on just the specific sections that have been covered in lecturer notes (Van Meter, Yokoi, & Pressley, 1994) or on tasks and exercises that are assigned for homework (Randahl, 2012; Weinberg, Wiesner, Benesh, & Boester, 2012). Lithner (2003, 30) observed that students commonly aim to reduce the complexity and academic demands of their study tasks, so limit the scope of their study material, and focus on learning short-cuts and procedural reasoning. Thus while the textbook may be an authoritative document, for lecturers, views of students here affirm the observation of Ramsden (2003, 153), that the level of detail and formality reduces their accessibility to students.

A number of students expressed the view that the textbook was too expensive, and too bulky, with an e-book format suggested as a better option:

> Gets heavy, PDF are easier to carry on Tablets without having extra weight;
>
> too hard to navigate; online makes it easy to access (e-book)

The issue of student preference for e-textbooks or physical textbooks (Daniel & Woody, 2013; Rockinson-Szapkiw et al., 2013; Stone & Baker-Eveleth, 2013; Woody, Daniel, & Baker, 2010) is evolving along with hardware and software developments. Again, support for handwritten annotation has been identified as a factor influencing student acceptance of online materials (Dennis, 2011). Clear strategies are required for effective use for instructional purposes (Hao & Jackson, 2014), with design and functionality developed appropriately for the medium (Yerushalmy, 2014).

Coursebooks

Coursebooks provide an abbreviated and simplified version of the more complex material in a formal textbook, while maintaining a printed form. Coursebooks were rated more highly than textbooks and social media by both subgroups, with no significant difference between the class subgroups, despite differing coverage and availability across classes. Of students who commented on the resource, 41% provided positive comments:

> lets you know what content to study; shows all information; the only resource I use; good format, cheap

However many students (48% of those commenting on the coursebook) proffered negative comments, suggesting coursebook notes had insufficient detail, or lacked sufficient examples:

> needs better explanations and more practice questions; needs additional examples of easy and medium levels instead of going straight to difficult; the worked examples are not very good and are missing too much intermediate working steps.

As with textbooks, some students commented negatively on the physical format:

> becomes difficult to manage, bulky and heavy; depends on weight and portability;

Lecturer Generated Static Resources

It was apparent in student comments that there was some overlap and ambiguity in how students interpreted the term for these resources. In the survey, lecturer notes ('Lecturer notes in [the LMS]') and PowerPoint slides ('Lecture PowerPoint Slides in [the LMS]') were intended to represent notes available online for reading before lectures. Handwritten lecturer class notes ('Copies of handwritten notes as recorded in the lecture and made available as PDFs or OneNote pages') were intended to represent post-lecture records. However, some lecturers posted PowerPoint slides with annotations after the lecture, and another lecturer had included copies of PowerPoint slides within OneNote pages that were made available to students live online, and annotated and extended in class. While student comments are quoted below for each of these resource categories individually, given the likely overlap in interpretation it may be more appropriate to consider these as a combined category of ‘Lecturer provided online static resources’.

In general, these lecturer generated class materials were regarded by students as more effective than textbooks, coursebooks and social media. Overall, AAE classes rated lecturer-generated materials more highly than those in the BEM classes (Table 2). This might be explained by AAE classes being more reliant on lecturer-generated materials customised to the class.

PowerPoint Slides

These were the lowest rated of lecturer-generated resources, particularly for BEM classes. Comments reveal a range of lecturer practices, with some lecturers making slides available before class, and others not, some including worked examples and others not.

> Very useful when put up [online] ahead (of) lecture can be printed to add notes onto it; wished some lecturers uploaded it early; useful as able to write notes on them; same as lecturer notes;
>
> usually missing important verbal information; too basic, essentially (when) just prompts; (very lecturer dependent);
>
> none of the examples are answered in slides; due to worked examples the slides were good

Lecturer Online Notes

Student comments suggest a range of practices in how such notes are provided, and differing student interpretations of the category (particularly in relation to post-lecture notes):

> Allows to go back and see what the lecturer meant and how he has done it; explains the lecture well; depends entirely on the lecturer; usually available after lecture; only if titled and organized; gives us better idea of what is required; helps by showing proper way to do exercise; good revision; great for study.

Comments show that in one class, a student interpreted the ‘lecturer notes’ category as including notes in screencast video format.

> His notes are in video form, very clear and highly available for review.

Handwritten Course Notes

Student comments again reveal a range of lecturer practices in provision of handwritten notes:

> If missed class it is handy to have; 10/10 would study; Would be great; available as PDF or OneNote file would be amazing; sometimes when missing notes (it) helps fill the gaps; it is helpful to get summaries of topics written by lecturer; this would be very helpful as you can review problem methods; could be unclear, too messy.

Other comments note limitations of written notes:

> Notes are made while talking - seeing notes without having what was said leads to confusion; need the explanation; easy to get lost without teachers interaction.

Live Multimedia –Videos, Lecturer Screencasts and External Resources

The final group of resources considered here are those with a multimedia format –lecture video, screencasts and external online resources.

Video recordings of live lectures

In the context of this study, a universal lecture capture capability was not available within the institution, although some lecturers had made specific arrangements for lecture recording. Student comments suggested that while they may have had limited experience of lecture videos within their current study, they were supportive of their production, with 45 of the 64 comments indicating that students would like recordings to be made, particularly to cover classes they might miss (5 students).

> Videos of critical topics would be useful to recap especially if they are complex; would love the option of going over some lectures that I have struggled with or even missed; very good in case of missed lecture, or if I did not understand it the first time; would be good to go over things twice; some students have to juggle work; not many lecturers use this method; would prefer more lectures to be recorded.

Some students who had had previous experience of recorded videos commented on issues with poor quality of recordings (4 students):

> Often bad audio can ruin these, cameras struggle with whiteboard contrast; Sometimes are low resolution. They should be rerecorded! Quality of video could be a little better though.

Students also commented on the length of recordings being an issue:

> Can't be bothered watching whole video; sometimes too time consuming; (record) not all of lecture, just main concept + example

Lecturer Prepared Screencasts

Lecturer Prepared Screencasts were defined in the student survey as ‘Lecturer prepared screencasts (i.e. recordings of handwritten material with audio)’. While not a standard class resource (at the time of the survey), comments were generally supportive of the concept:

> Not used widely in these courses; interesting concept; Can also watch in own time. this I feel would be most effective for studying; would be good to have these like [as used in other class]; will be very useful if material is able to be played at home.

Again, overall ratings were not significantly different between AAE and BEM subgroups.

While video and screencasts were rated as better than textbooks and coursebooks (and social media), they were rated as not significantly different to lecturer-generated static notes for BEM classes, and for AAE classes, slightly worse or not significantly different (Table 3, 4). This may be reflective of them not being a standard class resource (at the time of the survey), with a high proportion of respondents indicating no opinion or offering no response (24% for video and 27% for screencasts).

External resources

External resources, defined in the survey as ‘External online resources (e.g. Khan Academy)’, covered a range of resource types, including screencasts (Khan Academy), lecture capture videos (MIT resources) and interactive websites (Wolfram Alpha).

Table 6 lists resource sites most frequently mentioned by students, leading with the Khan Academy (http://www.khanacademy.org), mentioned by 72 or 15.0% of all students. YouTube (https://www.youtube.com), which is mentioned by 10.8%, provides access to a range of resources, including dedicated channels providing access to materials from the sites listed previously, including the Khan Academy. The Patrick JMT site (http://patrickjmt.com/) which is mentioned by 3.1% of students also offers mathematics-specific content in the form of short (typically around 10 min or less) video or screencast tutorials, with the instructor heard but not visible (apart from a hand). Resources on the MIT OpenCourseware website (http://ocw.mit.edu/index.htm) include many full lecture videos (of nearly one hour) for a wide range of subjects, and were mentioned by 1.5% of students. Wolfram Alpha (http://www.wolframalpha.com/) provides computational tools that allows problem solution with symbolic as well as numeric input and output.

While many student comments only noted the names of sites they used, a number of comments mentioned the particular benefits of being able to view procedural steps in detail, at their own pace, and having the opportunity to replay videos:

> Excellent pace and explanations. The [online] tutor assumes we know very little so doesn't skip steps; I always use as explanations are very good; This is really good way for us to go back and do the same thing over and over again; Youtube demonstrations I find are very useful. If I don't understand

> something I can watch it at my own pace; Using Youtube to look at some lessons that I did not understand in class; youtube videos related to any topic that I am struggling with; Very good as they spend lots of time on explaining equations; I always use as explanations are very good.

While these external video/screencast resources were not set as prescribed resources, it is noteworthy that students in BEM classes had located them and used them widely, and rated them higher than all other resource types. That AAE classes assigned this category a rating lower than all other resources apart from textbook and social media might be explained by the fact that specialised material appropriate to the course was not readily available. This was explicitly noted by a student who, in giving a 'very ineffective rating', commented that the "courses being studied are too advanced in almost all cases" for suitable resources to be readily found. This echoes a similar assessment from an advanced student as noted by Smith (2016).

Assessment Focus

At the study university, the assessment requirements for a particular unit of study (called a paper) are described in a document called a Paper Descriptor. The Paper Descriptors for the BEM classes assign 20% of the course marks to assignments, 20% to tests and 60% to a final examination. Inspection of examinations and tests for these initial mathematics classes show a strong emphasis on procedural questions. This focus on procedural fluency has been recognised as a feature of undergraduate calculus elsewhere (Tallman et al., 2016), with conceptual knowledge much harder to assess (Crooks & Alibali, 2014).

Assessment requirements for AAE classes also show a high emphasis on timed examinations and tests. These courses mostly allocated 70% to a final exam (generally of 2 hours) with remaining marks allocated to tests and assignments. An exception was an engineering design paper, with 30% allocated to a project, but still 50% allocated to a final timed exam. Examinations for the AAE classes (AAE) placed more emphasis on problem formulation, often requiring interpretation of diagrammatic representations of problem situations, and selection or derivation of appropriate mathematical formulations. However, while problem formulation required a level of conceptual understanding, a majority of the mark allocation was for carrying out the standard procedural techniques appropriate to the described problem.

Skemp (1979, p. 259) defined instrumental understanding in mathematics as "recognizing a task as one of a particular class for which one already knows a rule." In fact, in many of the exam questions in the BEM classes the students did not even need to recognise the particular class of problem, with the procedural method being specified ('Hint: use substitution'). In a sample examination paper in a first year engineering mathematics class, the whole of the first section, worth 55%, could be completed by entering the stated equations into Wolfram Alpha, without requiring any problem formulation or interpretation. As Skemp (1976) notes, there may be a range of reasons why classes may focus on instrumental understanding, including it being easier to convey, giving immediate rewards, and allowing fast completion. Instrumental understanding can also be easier to assess. A formal individual examination format that emphasises demonstration of procedural techniques can be standardised for timing and easily graded, with marks allocated with reliability and precision. It is not uncommon for previous exam papers to be reused with just a simple change of coefficients or substitution of algebraic function.

Findings

Students at both levels rated lecturer-generated materials as significantly more effective than formal published materials (textbooks) or social media, for study outside class. This may be explained in that lecturers naturally focus lectures on material that will be assessed (or conversely, will base assessment on what is explicitly taught in lectures), and thus students will rate lecturer-generated resources as most effective, as being closely aligned with expected assessments. In this respect, student perceptions of resource effectiveness might be explained as being in alignment with the learning expectations implicit in the subject. These ratings reflect the findings of Rensaa (2014) and Hegeman (2015) noted earlier.

As well as having a focus on problem solving procedures that are likely to be examined, lecturer-generated material may be more accessible to students than commercial materials; a lecturer's handwritten solution of a procedural exercise will model closely both the form and substance expected of students in assessments. However, for the complex material in mathematically intensive disciplines, even the informal handwritten version will lack important sequential development with accompanying verbal commentary. As a student commented here, they "need the explanation".

The highest rating of any resource was that given by BEM students to Khan Academy style resources. This may be explained in that they show the processes on which students will be examined in a multimedia format that includes this sequential development along with verbal explanations. The lower rating of external resource sites by AAE students may be explained by the low availability of resources appropriate to the specialised nature of those subjects. While at the time of the survey suitable screencast material was not readily available for the more advanced subjects, either on external sites or as lecturer generated material, ongoing developments within the study university have been directed toward developing suitable resources for some courses.

Although recordings of hour-or-more long lectures may be a useful resource for students who have missed a lecture, they may be of limited value for those who have attended; as noted in the student comment here, repeat watching may be "too time consuming" to be effective. These comments reinforce the findings of Guo et al (2014) that short focussed screencast material may be more effective. Provision of full-lecture videos might be seen as an attempt to compensate for fundamental issues many students may have with the pacing, duration and high content density inherent in a transmissive lecture format.

Student views of teaching approaches, and their views on resource effectiveness, may be expected to be strongly linked to expectations of the nature of the knowledge to be assessed. Changes to teaching approaches that aim to give more emphasis to developing conceptual knowledge will necessarily include similar changes in assessment focus. Thus peer-learning approaches developed by Mazur (Crouch & Mazur, 2001; Fagen, Crouch, & Mazur, 2002) involve assessing students' conceptual development using tools such as the Force Concept Inventory (Hestenes, Wells, & Swackhamer, 1992).

While development of procedural fluency has traditionally been reliant on live modelling by the lecturer in the classroom, it is apparent that students regard screencast material, when available at an appropriate level (as in the Khan Academy for BEM classes), to be effective learning resources outside the classroom. This may facilitate the use of active learning approaches within the classroom that place more emphasis on “student-centered investigations, problem solving, communication, and collaboration” (Guerrero, Baumgartel, & Zobott, 2013, 173). These active learning approaches have been shown to encourage conceptual development (Deslauriers, Schelew, & Wieman, 2011; Kober, 2015; Wieman, 2014).

Conclusions

A critical concern in engineering and mathematics education has been the development of foundational procedural knowledge in conjunction with conceptual understanding. A key student focus within the traditional classroom, reinforced by assessment expectations, has been on the lecturer’s modelling of the procedural techniques involved in problem solving. In this study, students regarded dynamic screencasts, where appropriate material was available, as an effective resource for developing procedural understanding. If developing procedural fluency can be addressed using such resources outside class, pedagogical transformation may allow more in-class time to be used effectively for other activities.

It is apparent that the successful introduction of alternative pedagogical approaches will require adoption of changes in both the focus and format of assessments, to place greater value on evaluating conceptual understanding, while not neglecting the importance of developing procedural fluency.

This study has investigated student use of resources within traditional teaching models. The findings may also be applied to support development of more effective teaching approaches.

References

See References section at end of Thesis.

CHAPTER 10 / STUDENT AND LECTURER VIEWS ON NOTETAKING

Overview

In terms of a DBR approach, the initial developments were based on enhancing the presentation of the in-class lecture. However, some lecturers had made use of the functionality of the penTPC to make digital recordings and share them online. As discussed in Chapter 5, one of the features of the penTPC environment was the capability to provide access to lecturer notes; students valued technology modes that:

- can provide a record of notes that can be made available online (notes access).

This included material that was developed and recorded in class and, in some instances, material developed and recorded outside class as screencasts. It is suggested that a systematic approach to make use of this functionality could provide an opportunity to support more substantive changes in the teaching approaches; in SAMR model terms (Puentedura, 2010), to move from use of the technology for substitution and augmentation, to support modification and redefinition of pedagogic approaches.

It has also been suggested that new technologies can provide new ways of generating, recording, organising and storing information that can impact on traditional approaches (Bui & Myerson, 2014), and that the introduction of new technologies should be accompanied by a re-examination of traditional notetaking practices (Stacy & Cain, 2015). This chapter examines in more detail traditional approaches and attitudes towards notetaking, the attitudes and practices apparent in the classes surveyed, and how notetaking practices might develop to take advantage of the penTPC technology. A revised conceptual framework is used to establish potential design conjectures for future DBR developments.

Conceptual Framework - A review of the literature on notetaking

> *A lecture is a process in which information passes from the notes of the lecturer to the notes of the student without passing through the minds of either.*
>
> (Friley, 1930)

That the definition of the lecture above has remained a popular quote from as early as 1930, in a range of variations and with differing attributions (Huff, 1954, p. 46; Shuhaiber, 2015; Stephenson, Brown, & Griffin, 2008), recognises both the longevity of the lecture form and the ongoing criticisms of its potential limitations. While alternatives to the lecture are discussed, in this chapter attention is directed to a core component of the traditional lecture - the lecture notes, as developed by the lecturer and as acquired by the student.

While a range of pedagogic approaches exist within the study university, the approaches observed in this study of mathematically intensive (MI) engineering subjects remain consistent with a lecture form that has been predominant in engineering disciplines for many years (Allendoerfer, Kim, Burpee, Wilson, & Bates, 2012; Berrett, 2012; Fairweather, 2008, p. 12; Felder, 2012; Goodhew, 2010, p. 27; Love, Hodge, Grandgenett, & Swift, 2014; Mills & Treagust, 2003; Murphy & Candlin, 1979; Shulman, 2005b).

Just as the lecture session has been regarded as a fundamental responsibility of a tertiary lecturer (as manifested in the job title), notetaking has long been regarded as a corresponding responsibility of students (Carrier, Williams, & Dalgaard, 1988; Titsworth

& Kiewra, 2004). Notetaking has been suggested as acting to enhance learning in two ways: enhancing the storage function by facilitating retention of facts, and by supporting an encoding function that encourages "increased attention, more elaborative processing of specific ideas, and/or greater organization of lecture material" (Kiewra, 1989, p. 149).

It has been suggested that the use of handwritten approaches is an essential component of mathematical thinking and teaching (Artemeva & Fox, 2011; Greiffenhagen, 2014). Mathematical and scientific disciplines make use of a range of different registers of representation, including sketches, handwritten expressions, graphs and annotations, (Bunt, Terry, & Lank, 2009; Kober, 2015; Lemke, 2004), that are closely integrated in developing procedural techniques and exploring concepts. Mathematical disciplines require students to build familiarity with the complex notation and layout of symbolic forms (Sherin, 2001), where even the spacial layout of handwritten equations can carry syntactic meaning (Landy & Goldstone, 2007).

As Gibbs (1981 in Rensaa, 2014) suggests, it is apparent that any physical act of notetaking has some intrinsic value, in at least maintaining students' attention. The engagement of the hands in a writing activity may aid concentration, with research linking the physicality of handwriting with enhanced learning (Anthony, Yang, & Koedinger, 2008; Aragón-Mendizábal, Delgado-Casas, Navarro-Guzmán, Menacho-Jiménez, & Romero-Oliva, 2016; Mangen & Velay, 2010; Mueller & Oppenheimer, 2014; Oviatt, Cohen, Miller, Hodge, & Mann, 2012); even doodling while listening has been shown to have potential advantage in aiding concentration (Andrade, 2010).

Since student performance has been linked to the quality of their notes (Johnstone & Su, 1994; Reed, Rimel, & Hallett, 2016), it is critical that notetaking is carried out effectively.

Taking high quality notes may be particularly important in MI classes because of the quantity and complexity of content covered in each session, and because the hierarchical nature of the content structure requires solid grounding in lower level concepts before progressing (Cardetti, Khamsemanan, & Orgnero, 2010). However, it is apparent from research across many disciplines (Johnstone & Su, 1994; Kiewra, 1985; Titsworth & Kiewra, 2004), including MI disciplines (Cardetti et al., 2010; Davies, 1976; Lew, Fukawa-Connelly, Mejía-Ramos, & Weber, 2016; Rensaa, 2014; Weinberg, Wiesner, & Fukawa-Connelly, 2014), that many students do not take effective, accurate and complete notes.

Weinberg et al. (2014, p. 177) found that students "often omitted aspects of the instructor's writing from their notes when they did not understand the mathematical content, the purpose for including it in the lecture, or how the content was related to other mathematical ideas".

Research also suggests that it is not the taking of notes that is most important in increasing student performance, but the reviewing of notes (Kiewra, 1985; Kobayashi, 2006). Taking notes but not reviewing them has been found to be no more valuable than just listening (Kiewra et al., 1991). Palkovitz and Lore (1980) found that students who had not consistently reviewed their own notes during semester were unable to answer questions on material, even where it had been accurately recorded. While students who review their own notes do better than students who do not, it has also been noted that students who review instructor provided notes do even better, and students who review both their own notes and instructor notes may do best of all (Kiewra, 1989). The next sections discuss the attitudes toward notetaking that were evident from the surveys of students and staff.

Conceptual Framework – Evidence from this Study

This chapter reports on analysis of additional data from the surveys reported in Chapter 5. This data arose from the survey of eleven lecturers using penTPCs as a classroom presentation technology for teaching MI engineering subjects within the university, and the related survey of 480 students who had experienced this form of teaching. It again uses a mixed methods approach, as discussed in Chapter 5, aligning quantitative analysis of Likert-style questions with a qualitative content analysis of written comments. A thematic analysis method was also applied to these comments, involving six phases as described by Braun and Clarke (2006).

Student opinions were surveyed in six distinct (date, time and location) class sessions involving six different lecturers and five different MI subjects. The sessions chosen were essentially a convenience sample, selected on the basis of lecturer use of a penTPC, and timetabling availability. The classes covered a range of levels, from initial undergraduate mathematics through to more advanced and applied engineering subjects. While the survey was conducted within classes in which the lecturer used penTPCs as a presentation technology, student feedback reflects attitudes and experience across their study discipline. The anonymous paper based survey resulted in 480 survey returns, representing over 95% of students present in the sessions. Students were asked for their assessment of the importance of notetaking on a 5-point Likert scale, the format they used for their notetaking, and for comments on different approaches to notetaking and note provision.

Lecturer opinions are reported from eleven lecturers, all of whom were using penTPC technology in teaching MI subjects, including all six lecturers involved in the student survey sessions. The aspects reported in this study relate to lecturer expectations of student notetaking and student use of notes, and to lecturer approaches to the provision of their own class notes. The study also references other informal unstructured feedback from lecturers and observations of sample lessons. The lecturers in the study were all experienced teachers within the disciplines of engineering and mathematics. While not claimed to be a representative sample, the lecturers would not be considered to be atypical in their teaching approaches, apart from perhaps their early adoption of penTPC technology. Even though the number of lecturers surveyed is relatively small, as a focus group they may provide useful insights into evolving practices of use of penTPCs within the university (Nielsen, 2000; Tang & Davis, 1995), and help form conjectures for future cycles of development.

Results

Lecturer Views on their promotion of, and student engagement in notetaking activities

The lecturer survey asked lecturers to record their level of active promotion of student notetaking activities, and their perceptions of the extent to which students actually engaged in those activities. Figure 1 summarises the results on four aspects: whether students should/did take notes; whether students should/did take (specifically) handwritten notes; whether students should/did revise their own notes; and, if lecturers provided their notes, whether students should/did revise those lecturer notes. The response 'XA' in the latter case indicates that lecturer notes were not provided. It is noticeable (Figure 1) that while most lecturers perceived that students participated to some extent in notetaking, they had lower expectations, or no perception, of students' actual engagement in notetaking review activities.

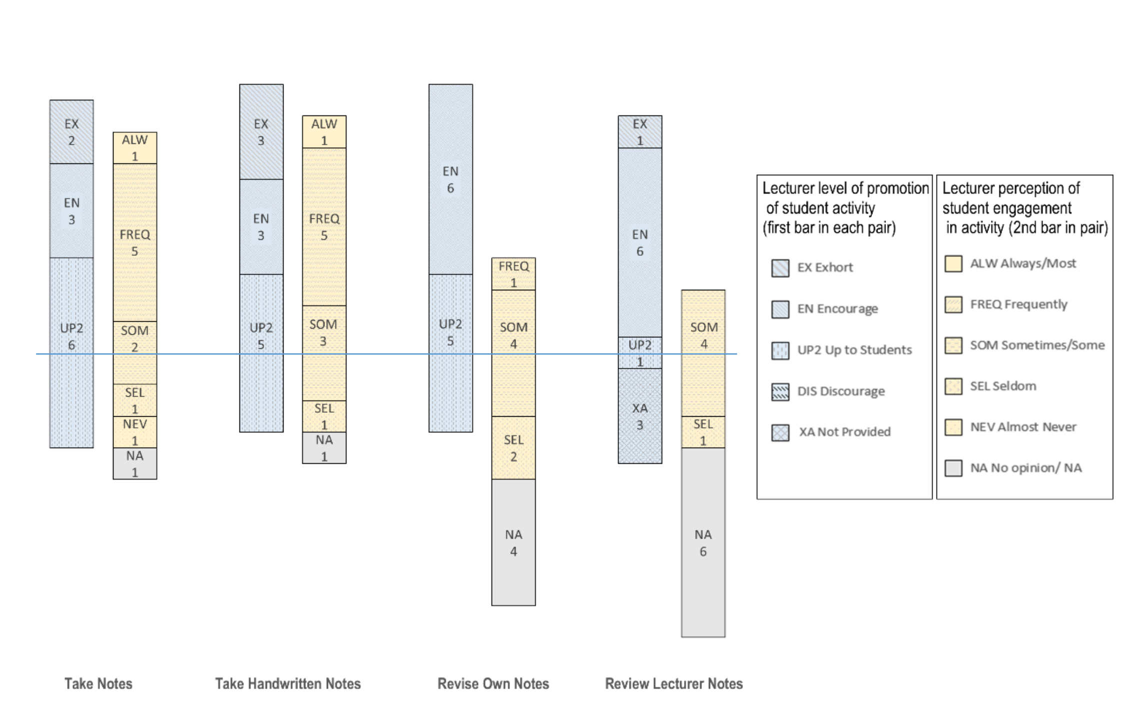

Figure 1. Lecturer promotion of activity and perception of student engagement. Numbers on bars show the number responses for each rating. The vertical placement of each bar is adjusted to align the midpoints of the middle categories. Sample size *n* =11

Lecturer Attitudes to Handwriting Their Notes

Previous research has identified the capability of the penTPC to enable a handwritten approach as being a factor influencing its acceptance as a classroom technology (Maclaren et al., 2017a). Lecturers were asked their view on the importance of themselves using a handwriting format in delivering lecture content from which students would take notes. Seven of the eleven lecturers regarded a handwritten approach as extremely important/vital, and the other four regarded it as important/necessary. Key themes in their reasons are identified below, together with representative lecturer comments (quoted verbatim):

Controls pace and is a format appropriate for mathematical material.

> *Slows me down; would not be able to teach maths without handwriting; user friendly for the students (they handwrite their tests, exams and assignments); allows student learning in the class in mathematical courses; You cannot do everything in PowerPoint!*

Demonstrates process.

> *Process rather than the product/result; dynamic rather than static; it is much better for learning when students see the process of solution step by step and participate in it; I involve them by asking questions and getting answers; based on their answers I see what steps can be skipped and what should be explained in more details; for a math based paper, it is very importance for the students to see the process or the steps.*

Combines different representations.

> *Can draw sketches to make derivation easier to follow; without the students seeing me write (equations) and draw (graphs and diagrams) they would not understand how their hands are going to do it in the future; I believe the typescript and textbook images of graphs and diagrams do not give students any clue as to how to do it themselves; aside from academic credibility, it is very helpful to simultaneously talk and direct, by drawing, the students through complex engineering problems; Impossible to explain some concepts without written annotations.*

Lecturers are explicit about the positive effect of a handwritten format in slowing them down and enabling a dynamic demonstration of process. It is also clear that the oral commentary is regarded as an important, integrated component of the session content.

Lecturer Approaches to the Provision of Their Notes as Developed in-Class

In using a penTPC to create handwritten notes, lecturers were creating a digital record of what they developed within the class session. However, across the 11 lecturers using a penTPC that were surveyed, there were different attitudes expressed as to whether these records should be shared with students. While the sample size was small (*n*=11), the range of responses revealed inconsistent approaches, with different perspectives on both the desirability of, and mechanisms for, note provision. These different approaches may be characterised:

A: Don't/won't provide class-developed notes to students.

B: Class notes are provided as static (PDF) documents, posted to the learning management system (LMS) after class.

C: Class notes are provided through access to live (OneNote) documents.

D: Class notes provided through access to recordings of OneNote sessions

Three lecturers indicated they did not provide their class notes to students. One lecturer was clear that they regarded it as important that students needed to take their own handwritten notes:

> *I do not provide my handwritten (notes) as I want them to take their own. For Engineering related papers it is extremely important, in my opinion, that students take their own notes and write down solutions as you write them up and explain them on the board/tablet. The process for a solution is important and processes are best learned by doing/practising them.*

This importance placed on students handwriting their own notes was reiterated in a lecturer comment on student taking of photographs of board work:

Some take intermittent photos. I really want them to write and I tell them so.

At the other extreme in attitudes to making their notes available, one lecturer had developed a practice of making the OneNote notebook available to students live during the session, and also recording the session as a screencast that was posted online after the session. In one class video recording of some lectures had been carried out but this was not a standard practice within the university at the time of this study.

Lecturer Use of Presentation Material That Was Prepared Pre-Class

While the lecturers observed in this study all used the penTPC to develop handwritten solutions to sample problems within class sessions, different approaches were observed in the inclusion of static prepared material. Most static material was predominantly theory (typewritten) or textbook-style completed diagrams and problem statements delivered in the form of PowerPoint or PDF slides. In general, the density of content in these slides would be too much for students to transcribe fully as their own notes. In most instances (but not all) slide material was available to students before class in hardcopy or printable format, and often included space for the student to copy lecturer annotations and add their own notes. This provision of partially complete materials allowed students to keep pace where material involved complex diagrams.

One lecturer had developed an approach in which prior to class OneNote pages, constrained to a printable A4 size, were carefully prepared with the example problem text and relevant diagrams and made available to students. During the class session, conscious attention was given to producing notes in the form of a carefully constructed "model solution" within the constraints of the pages. The students could copy their own version as the lecturer version was developed, but also had access to the lecturer's completed notes (as a PDF) following the session.

In an alternative approach, another lecturer included the (former) PowerPoint slides as images within pages in a shared OneNote notebook. This provided students with live access to this material, along with subsequent annotations, and additional handwritten material as it was developed in class, all in a single online location.

Student ratings of the importance of Notetaking

Students were asked to indicate their level of agreement that "Taking notes in class is important". The majority (88%) of the students agreed, with 48% indicating 'strongly agree' and 40% 'agree' (Fig 1.). However, 8% of students were neutral (indicating they neither agreed nor disagreed), and 17 (4%) disagreed (including 1% who strongly disagreed). These results are displayed in Figure 2.

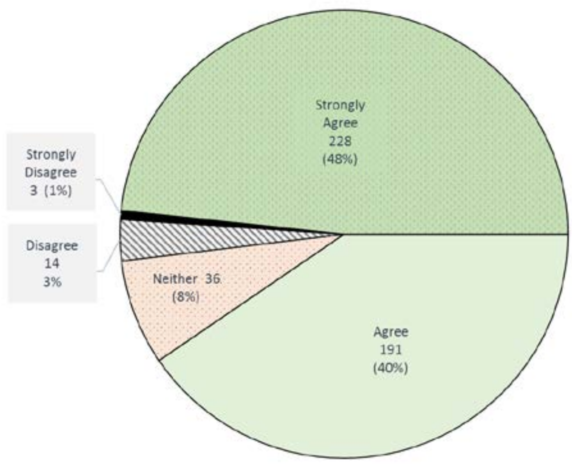

Figure 2. Student agreement that "notetaking is important" (*n*=464).

Student Comments on importance of Notetaking

Thematic analysis of student comments on the importance of notetaking revealed the key themes listed below (along with sample student quotes):

Helps understanding of process (36 students, 23%)

> *To understand concepts and problems; to understand the process; shows working process; helps clarify my understanding at speed at which I understand; most important is getting an understanding and process for example questions; I want to follow what's going on.*

Needed for review (33 students, 21%)

> *Effective learning is done outside of class when reviewing notes. Something to look back on after class; I am able to look back on what I have learned and revise; It is easy for me to review the knowledge and prepare for the exam; To review after lecture and to use for study; For reviewing at a later stage its critical; So that I could go over it again later; is essential part of learning and key to having good study material; because you need something to review while you study; To have notes for later referencing*

Helps to remember (25 students 16%)

> *Good for memorizing; writing helps you remember; writing down helps in making the information sink in better; it sticks in your mind if you write it down, also gives a reference point in notes; written notes leave deeper impression in mind; can't remember all aspects of class, notes provide that info; helps with retention; I forget if I don't; just to use as reminders when studying; help me remember, and vital for future study; it sticks in your mind if you write it down, also gives a reference point in notes; otherwise too confusing with slides; too easy to forget important rules if they aren't written on the spot.*

Lecturer provides important content in class, additional to prepared/supplied content (17 students, 11%)

> *Because there are some things that are not stated in the lecture notes but said in class; lecturers say important points that are not on the slides; because some things may be explained in class but not on the slides; important points are needed to note down for self-direct learning and compare to what's internet available; because its written, so it's important; it helps in getting the feel of what is expected in tests and exams; to fully understand the content & pick up extra points from the lecturer.*

Personalised notes (15 students, 10%)

> *Always helps to hear and write to remember using own words. you are able to understand your personal notes better; personal notes makes understanding easier; helps remember what you learned in your own words; taking personal notes is important for retention of knowledge; it's my understanding of the topics with my own annotation and explanations; although info is in textbooks your own notes gives you more understanding.*

Engagement in class (12 students, 8%)

> *Because [it means] that you are attentive in class; gets you more focused; forces you to pay attention; keeps you engaged; gets you involved and thinking; to keep concentrated and understand; writing down helps in making the information sink in better.*

Use for practice/tests/exams (5 students, 3%)

> *It helps in getting the feel of what is expected in tests and exams; the practice of questions is important; can simplify explanations, what to write for exam explained; cover the main points for tests and exams; notes are important for revision for exams and tests.*

Almost all students (98%) indicated that they actually took notes at some time, although only 88% had indicated that they thought notetaking *important* or *very important*. In general, students appeared to accept the standard lecture model in which their role was to take notes, to record the important details for their future study and review, and as an aid to engagement in class. However there were some students who commented on the difficulties imposed by writing while listening, and how that might impact on important material being missed.

Listening rather than writing (13 students, 8%)

> *So long as there isn't so much material that you spend all your time writing and not listening; sometimes it is good to take notes in class but this could lead to missing points said while writing notes; better to learn initial concept by paying attention than trying to copy everything down; I want to follow what's going on and not be busy writing; harder to listen to lecturer at the same time, but re-establishes information learnt; sometimes focussing on lecturer is better; good to have in own words, sometimes it is hard to do simultaneously to listening.*

Not needed (2 students, 1%)

> *Everything is in [the] textbook.*

Student Modes of Notetaking

Students were asked "Which of the following notetaking methods do you commonly use in lectures?" This data is depicted in Figure 2. A strong majority indicated that they handwrote notes, mostly using pen and paper (85%). A significant proportion (11% or 53 students) indicated they took notes on a Tablet PC (including 4% who also used paper on occasion). Only 11 students (2.5%) indicated they typed notes, and of those, only 5

(1%) did so exclusively using a laptop, with 4 (1%) using paper and a laptop, and 2 typing in conjunction with handwriting on a Tablet PC.

Students were also invited to comment on the reasons behind their choice of mode. Reasons given for handwriting included:

> *Too slow at typing, handwritten is more versatile and tactile; writing is much easier for learning but need [s]low speaking speed from lecturer; handwrite maths; much easier and faster; better memorization.*

Some students (48 or 10%) took photographs of the board on occasion, 16 (3%) recorded audio, and 12 (2.6%) recorded video at some time. However only 6 (1%) use exclusively digital forms, with the remainder using digital records to supplement other notes. Reasons for taking photographs include:

> *Sometimes taking photos if not enough time; occasionally photograph board for reference; photo if you do not have enough time to write.*

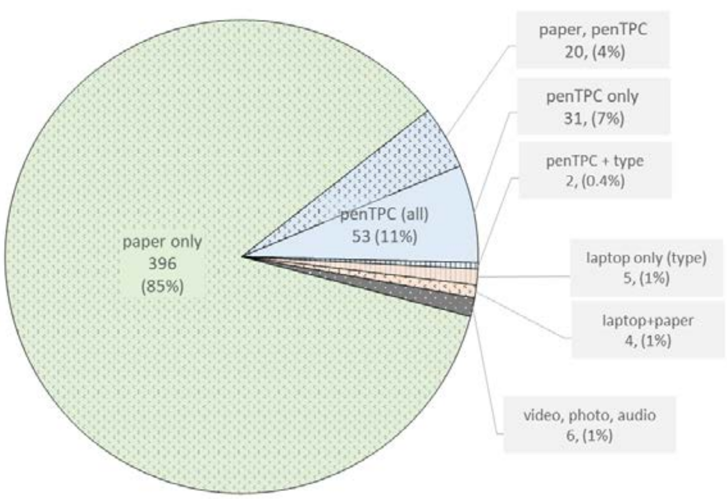

Figure 3. Student notetaking mode (*n*=464).

Student Views on Lecturer Provision of Notes

Students comments on lecturer-provided notes reflected the varied lecturer practices:

> *Usually available after lecture; No proper notes given, must take own notes; depends entirely on the lecturer.*

Some comments described the value of lecturer notes as being to clarify issues and indicate their importance, and to fill in gaps in their own notes:

> *Allows to go back and see what the lecturer meant and how he done it; it is helpful to get summaries of topics written by lecturer; gives us better idea of what is required; good revision; helps by showing proper way to do exercise; great for study.*
>
> *If missed class it is handy to have; sometimes when missing [own] notes [these] help fill the gaps; very helpful when recapping [and] missing [own] notes.*

However, some students commented on difficulties in interpreting lecturers' class-written notes without the oral dimension of the narrative:

> *Notes are made while talking. Seeing [lecturer] notes without having what was said leads to confusion; easy to get lost without teachers interaction; could be unclear, need the explanation; too messy; only if titled and organised.*

In one case screencast recordings of the class session were made available:

> *[Lecturer] Notes are in video form, very clear and highly available for review; explains the lecture well.*

Discussion

Current Lecture and Notetaking Practices in the penTPC Environment

In this analysis, involving MI classes where lecturers were using a penTPC, both lecturers and students regarded student notetaking as a critically important activity within the class sessions. Attitudes towards the key roles of the lecturer lecturing and students taking notes do not appear to have changed significantly with the introduction of penTPC technology.

The use of handwritten modes in notetaking was regarded as important by both lecturers and students, with 96% of students taking handwritten notes (85% on paper, and 11% using penTPCs). Students views of the importance of lecturers using handwriting mode have been noted previously (Maclaren et al., 2017a). Lecturers here also expressed their view that handwriting their notes was a critical feature of their lecture sessions in MI subjects, in both controlling the pace and showing the processes step by step, in order to facilitate student notetaking. Again, despite the affordances of penTPC technology that provide alternative ways to deliver content, it is apparent that there were still strong expectations that a significant function of the lecture session was the transfer of notes from lecturer to students with both using handwritten modes.

The belief that the act of hand-copying of lecturer (handwritten) material had intrinsic value was apparent in comments of both lecturers and students. One lecturer in the study made specific mention of the importance of demonstrating the physical process and sequence of the construction of equations, graphs and diagrams in a form that modelled what the students themselves would use, rather than just exploring a previously completed version. This echoes the view of Dreyfus (1995) who maintained that for diagrams, “not only their final appearance but also the manner and order in which they were built, their genesis is important" (p. 12).

Students also regarded notetaking as an important way of maintaining active engagement within a class session, as well as providing personalised materials for later review. Again, attitudes do not appear to have changed with introduction of the new technology.

Students appeared to place additional importance on the handwritten material that was developed live by lecturers: "Because its written, so its important"; "I only take notes if it is a worked example". While lecturers in the penTPC environment generally developed handwriting solutions to example problems, theory and conceptual material was often displayed as static slides (PowerPoint or PDF). As observed here, and elsewhere (King, 1994; Lew et al., 2016), students were focused on recording what is handwritten, reinforcing a corresponding focus on procedural material (Pritchard, 2010, 2015). This suggests that consideration needs to be given to how theory and conceptual developments are presented so that they receive appropriate attention from students.

As well as often being presented in static slides, key conceptual ideas are frequently delivered verbally in lectures, and not written down (Weinberg et al., 2014). While writing while using the penTPC slowed the pace of the written material, pacing is also important for ideas that are conveyed orally. As noted by one student, "[hand]writing is much easier for learning but need slow speaking speed from lecturer". As suggested by Hoong et al. (2014), it may be worthwhile for lecturers to consciously pay more attention to giving a live written form to traditionally non-written (verbal) conceptually-focused aspects to make them more explicit and likely to be recorded. One lecturer in this study has evolved a process of including such meta-commentary as explicit annotation text, written at an angle to distinguish it from the procedural development it describes (Wilson & Maclaren, 2013). This lecturer also uses the affordances of the penTPC to apply different colours for different aspects of a diagram. This can assist in the subsequent distinction of different functional components within the whole diagram. Students are advised when taking notes to follow the structure using different coloured pens to encode this information. However, colour based coding may need to be limited to supplementary information, recognizing that a proportion of students (and lecturers) may not be able to distinguish some colour variations (W3C, 2016).

Gestures may also be significant in communication (Alibali et al., 2014; Arzarello, Paola, Robutti, & Sabena, 2008; Radford, 2008), but information conveyed via gestures may be recorded even less consistently than information conveyed verbally (Roth, 2001). The use of explicit annotations (such as circles and arrows) in the penTPC environment as a written analogue for many gestures may result in more attention being given to recording those aspects in notes (Maclaren, Wilson, & Klymchuk, 2017b).

Possible Interventions to Improve the Notes that Students Take in Lectures

While lecturers and students were agreed on the importance of handwritten approaches and notetaking, there was a degree of mismatch between student and lecturers' perceptions of student involvement in this activity. While 88% of students regarded notetaking in class as important or very important, and five of the 11 lecturers (45%) positively encouraged notetaking, six lecturers (55%) regarded it as an activity that was *up to students*. While one of the lecturers thought that student engagement in notetaking activity was best described as *almost always/most,* and five as *frequently/most,* five (45%) either thought notetaking was not regularly carried out by most students or offered no opinion of student engagement in this activity (Figure 1). While lecturers mostly actively encouraged students to review notes outside class, they were less positive as to whether students actually did so (Figure 1). From a lecturer perspective it appears that the activities of student notetaking within a lecture session and student reviewing of notes outside class are regarded as a student responsibility, and not an activity that lecturers should monitor.

These attitudes might perhaps be regarded as a norm that is appropriate for a tertiary environment where the class lecture session is the lecturer's domain and the lecturers' non-involvement with activities conducted outside class, and notetaking in class, is consistent with a view of the students as adults responsible for their own learning. This is not to suggest that the lecturers are not engaged with their classes; informal comments from lecturers here suggest that engagement with students in the face-to-face lecture session is valued as an essential component of their role. Lecturer engagement in the lecture performance has been described by McShane (2004, p. 13): "[This lecturer] values the immediacy and physical proximity (speech, body language, engagement of senses) of face-to-face teaching. …. views lecturing as a performance and … wants students to feel they have 'missed something' by not coming to lectures".

However, in traditional board based lecture delivery, with the lecturer focused on the immediate physical performance, the notes they create are transitory board artifacts, erased as the lecture progresses. In that context students are reliant on their own notetaking performance for the provision of resources for use outside the classroom.

While these traditional approaches may be observed continuing in some classes in this study, some lecturers were actively using the technology of the penTPC and web-enabled sharing software to begin developing alternative teaching approaches.

Opportunities to use the penTPC to develop new approaches (or in SAMR model terms (Puentedura, 2010), to move from Substitution to Augmentation and Modification, and possibly to Redefinition of approaches are discussed in Chapter 11 following, framed in terms of potential DBR developments.

Design Conjecture A: Changed notetaking practices, traditional lecture approach.

As discussed in CHAPTER 5/ ARTICLE 2, the introduction of penTPC technology in the study university has essentially been as a substitute for whiteboards, with perceived functional advantages. Further analysis in CHAPTER 10 supports the view that pedagogical approaches have not changed substantially, with lecturers lecturing and students taking notes remaining as the primary classroom activities. As long as lecture based approaches remain a cornerstone of educational delivery, student success may be closely linked to the quality of notes that they take and review (or do not review). The study revealed a range of current approaches to issues of lecturer note-provision and student notetaking, with the introduction of penTPC technology extending the options available. Within the constraint of students retaining responsibility for notetaking, then use of the penTPC does little to change the design.

Potentially, the environment could allow the quality of student notes to be inspected by lecturers, as a portfolio. Other options include use of collaborative software to enable students to share their notes with one another, as well as the lecturer. However, this would require a change of approach from lecturers; what students do outside the classroom would need to become a direct concern of the tertiary lecturer.

The provision of lecturer notes developed live in OneNote (or other online software) appeared to be potentially the most significant development in the current pedagogic context. The provision of copies of lecturer notes, as developed in class, directly to students after class has not traditionally been a norm in tertiary teaching (Kiewra, 1989).

While this is now technically easy to do within a penTPC environment, lecturers in this study demonstrated widely differing views on how, or even whether, their notes should be made available to students. At one extreme, some lecturers were insistent that students needed to be present in class and make their own notes, and should not get lecturers' notes. For other lecturers, shared OneNote notebooks have become a valued resource, allowing notes to be shared even as they are developed.

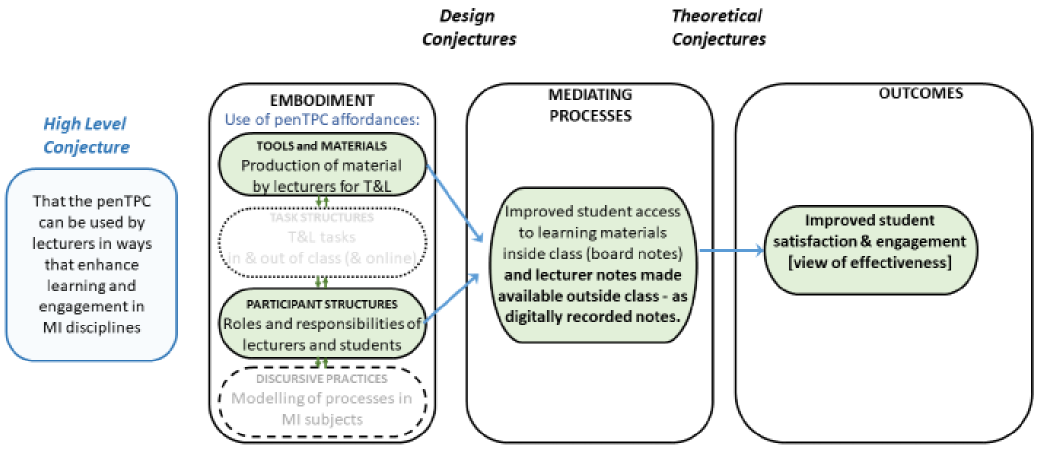

Figure 4. Conjecture map overview of penTPC project – lecturer notes provided.

While availability of lecturer notes would allow students to concentrate on listening, rather than notetaking, (a preference indicated by some students here), they will not then gain potential benefits from their own physical actions of copying and transcribing material into a personalised form. The provision of partially completed notes before class has been suggested as a way of encouraging attentiveness and engagement while enabling the student to acquire notes that are both personalised yet more accurate and complete (Cardetti et al., 2010). This approach was used by some lecturers here.

In using the penTPC in OneNote, some lecturers in this study worked with fixed page sizes, predetermined layouts and conventional document development flows. Others made use of unconstrained OneNote pages, and developed documents with a more irregular spacial layout and directional flow. As noted by some students, notes that may make sense when being presented dynamically may appear less coherent when presented in a static document, without audio commentary. While standard written material will generally follow a left-to-right, top-to-bottom flow development, diagram development and the addition of annotations may follow a sequence that is not apparent in a completed form.

Thus even where lecturers do provide access to their notes, the absence of dynamic and multimodal aspects of lecture development in the static written form remains an issue.

Design Conjecture B: Redefining the role of the classroom session

The potential provision of recorded video forms of notes, such as live lecture capture or penTPC screencasts, has implications for reconsidering the basic purposes and functions of lectures and notetaking. If students may take effective notes from recordings of lecture material outside class, then this invites reconsideration of the activities to be conducted within the class session.

There is the potential to use penTPC technologies in support of substantially different pedagogic approaches that are not lecture-centric. Evidence-based active learning approaches (Borrego & Henderson, 2014; Deslauriers, Schelew, & Wieman, 2011; Wieman, 2017), such as flipped classroom and peer-learning approaches (Crouch & Mazur, 2001; DeLozier & Rhodes, 2017; Wieman, 2014), involve use of classroom time for collaborative student activities, rather than for lecturer delivered presentations and student notetaking, with delivery of content occurring outside the classroom. PenTPC technology has a potential role in providing a capability to record lecturer expositions as dynamic digital videos, or screencasts. In capturing transient aspects of lecturer presentations (including audio), the screencast has the potential to facilitate more substantive changes, enabling these demonstration of procedural development to no longer be dependent on face-to-face classroom transmission. Indeed, the purpose of the lecture as traditionally defined might be subverted, with the digital environment allowing the dynamic notes of the lecturer to pass directly to the student without necessarily involving a lecture. Attention might then be directed towards in-class activities that move beyond a transmissive pedagogical model, and that seek to engage the brains of students not in copying notes, but in developing their own understandings.

The conjecture map in Figure 5 describes the basis for such an approach.

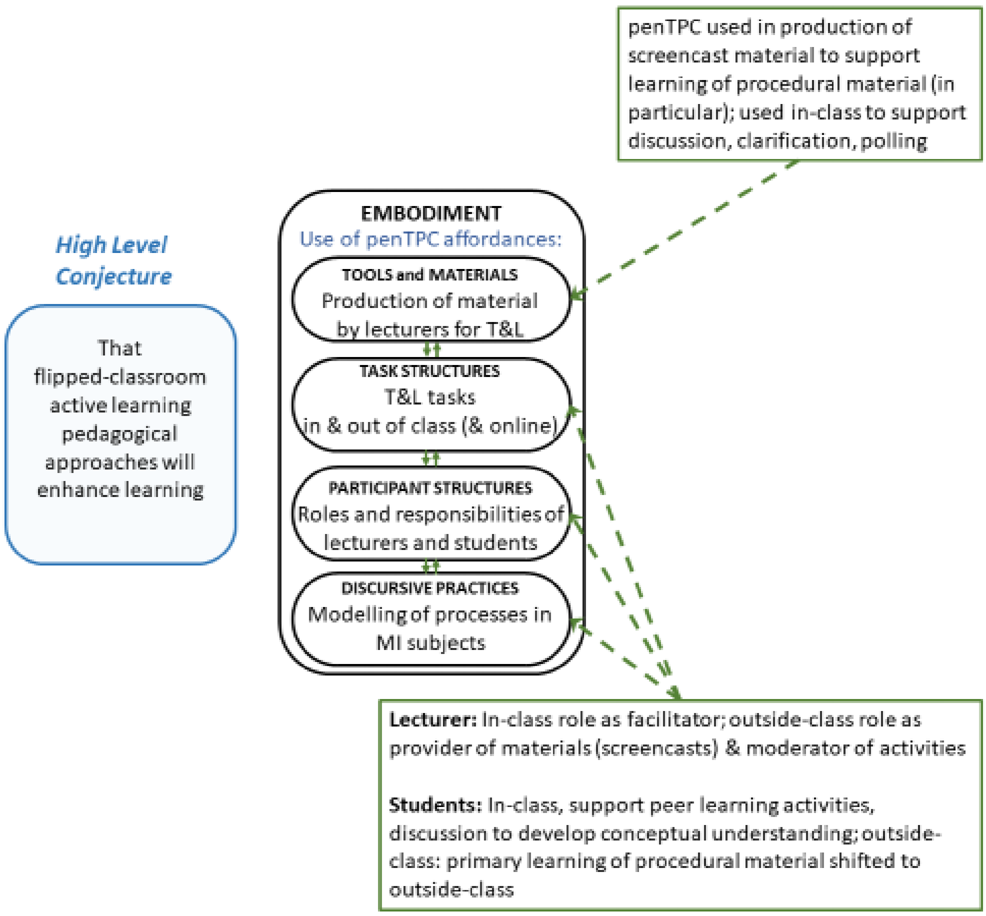

Figure 5. Conjecture map overview of penTPC project – flipped classroom - potential development of flipped approach with in-class discussion of concepts, delivery of material outside class.

Conclusions – Design development options

Future design cycles are required to investigate these options. The establishment of sound, consistent approaches to the issues of student notetaking and review is seen as an important area for research development. However, it is clear that there are fundamental differences in lecturer views as to the appropriateness of different directions for development. In looking to design processes for the effective implementation of penTPC technology it is apparent that, although some technical issues may remain, the most fundamental challenges may be in gaining agreement on the underlying pedagogical approaches to be developed.

Final Comments

This study explored factors influencing the introduction of an educational technology in a university, through a case involving pen-enabled Tablet PC (penTPC) technology. The initial findings were reported in journal papers that investigated different aspects of the initial cycle of technology implementation. A DBR approach was used in the analysis of the initial implementation and in suggesting future directions.

In this study two critical factors were identified as influencing the adoption of the penTPC technology. Firstly, in a university context, institutional support for the technology is essential to make it available, so that the individual staff members can make a decision about whether or not they want to adopt the technology. Secondly, in this study it was apparent that the penTPC technology was generally accepted because adopters saw it as relevant to what they were currently doing, as a better alternative to doing what they were currently doing (or would prefer to revert to doing) in the environment that had been imposed on them; critically, the technology did not demand any immediate change in their current pedagogical practices (or allowed a return to a preferred practice). It has been suggested that the introduction of a technology has seldom made a significant difference (Clarke, 1983, in Schrum et al, 2007) – but that has often been in situations where the underlying pedagogical approach has not changed. Salomon (2016) noted:

> the consistent tendency of the educational system to preserve itself and its practices by assimilating new technologies into existing instructional practices. Technology becomes domesticated which really means, that it is allowed to do precisely and only that which fits into the prevailing educational philosophy of cultural transmission. (Salomon, 2016, p. 152)

Thus we see the LMS frequently used just as a content repository, although it has the potential to do more. It may be not just that the technology is changed to fit the prevailing philosophy, but also that the technologies that are most readily adopted (or the aspects most readily adopted) are those that can be used within the prevailing philosophy. It appears that it is the modification/redefinition of pedagogical approaches that is difficult in itself (not the use of technology in support of those new approaches). Thus while use of new technologies may commonly be regarded as not driving pedagogical shift, it is not because the technology doesn't facilitate that shift, but that the pedagogical shift is difficult in itself.

However, to make the most effective use of a technology's pedagogical affordances it is necessary to identify the pedagogical approaches to which it will, or might, be applied (Schrum et al., 2007) – and establish a means by which adoption of those methods might be encouraged. While this study has initially focussed on the use of a particular technology, future directions for development need to focus on the form of educational development that is desired, and then establish how the technology of the penTPC might contribute. This study has identified potential opportunities to utilise the affordances of the penTPC technology to support active learning approaches, and suggests potential approaches for ongoing development.

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APPENDICES

Appendix 1 / Preliminary Student Fast-feedback Survey

Pilot Survey – Lecture Presentation Methods

This pilot survey is intended to give an early indication of the effectiveness of the use of pen-enabled computers for class lecture sessions. Any response is voluntary and will be anonymous.

Please try to answer these questions with a focus on the *presentation method*, rather than the subject material or lecturer, and assess the approach based on the sessions where technical issues have not interrupted delivery.

Q1 Compared to other delivery approaches in similar situations, I think that the presentation method, involving the projecting of live pen-developed screens, is:

- ⓐ Much worse
- ⓑ A little worse
- ⓒ About the same
- ⓓ A little better
- ⓔ Much better
- ⓕ No opinion/Don't know

Please mark your response by colouring the appropriate letter/circle.

Q2 Please comment on what you liked ***best*** about this presentation approach:

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Q3 Please comment on what you liked ***least*** about this presentation approach:

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Appendix 2 / Student Survey – Lecture Presentation Methods and Online Resources

Student Survey – Lecture Presentation Methods and Online Resources

This survey asks for your feedback on the effectiveness of different modes of lecture presentation.
Your participation in this survey is entirely voluntary and responses are anonymous. Your lecturer will not have access to these forms. Information will be collated independently and summary results will be made available to you and the lecturer. You may hand back this form as you leave, or to the researcher at the start of the next lecture session. **If you do not wish to participate you may choose to not complete a survey form.**

Instructions:
Please rate the following *approaches* as may have been used in your lectures, or that you use outside class, by ticking the appropriate box. Please add a comment with your rating. **Where possible give a general overall rating** or, if ratings vary widely depending on circumstances, please tick your high and low ratings, and state reasons for these ratings in the comments section.

A: This section relates to **In-class Lecture Presentations**

What is your rating of the different presentation methods? Rating Scale ->	N/A Not Used/ No opinion	1 Very poor/ Very Ineffective	2 Poor/ Ineffective	3 Average	4 Good/ effective	5 Very good/ effective
A1. PowerPoint slides on data-projector without in class annotation. **Comment (likes/dislikes) ->**	**N/A**	**1**	**2**	**3**	**4**	**5**
A2. PowerPoint slides with *live annotation* on data-projector **Comment (likes/dislikes) ->**	**N/A**	**1**	**2**	**3**	**4**	**5**
A3. Handwritten on whiteboard **Comment (likes/dislikes) ->**	**N/A**	**1**	**2**	**3**	**4**	**5**
A4. Handwritten on Tablet PC (e.g. in OneNote) and projected **Comment (likes/dislikes) ->**	**N/A**	**1**	**2**	**3**	**4**	**5**
A5. Handwritten on document camera **Comment (likes/dislikes) ->**	**N/A**	**1**	**2**	**3**	**4**	**5**

B: This section relates to ***your personal*** **notetaking in Class**

B1. **"Taking notes in class is important."** (What is your view of this statement?) **Comment (why) ->**	N/A No opinion	1 Strongly Disagree	2 Disagree	3 Neither agree nor disagree	4 Agree	5 Strongly Agree
B2. Which of the following notetaking methods do you commonly use ***in lectures*** ? **Comment ->**	None -don't usually take notes	Handwrite on paper	Handwrite on Tablet/ device	Type on laptop/dev	Take photo of board/ screen	Rec. audio Rec. video

More questions over the Page ->

C: Please rate how effective *you* find the following different resources that you may use *outside* class:

Rating Scale ->	N/A Not Used/ No opinion	1 Very poor/ Very Ineffective	2 Limited Use	3 Average	4 Good/ effective	5 Very good/ effective
C1. Coursebook notes (printed) **Comment (likes/dislikes) ->**	N/A	1	2	3	4	5
C2. Textbook **Comment (likes/dislikes) ->**	N/A	1	2	3	4	5
C3. Lecturer notes in AUTonline **Comment (likes/dislikes) ->**	N/A	1	2	3	4	5
C4. Lecture PowerPoint Slides (in AUTonline) **Comment (likes/dislikes) ->**	N/A	1	2	3	4	5
C5. Videos of live lectures **Comment (likes/dislikes) ->**	N/A	1	2	3	4	5
C6. Copies of handwritten notes as recorded in the lecture and made available as PDFs or OneNote pages **Comment (likes/dislikes) ->**	N/A	1	2	3	4	5
C7. Lecturer prepared screencasts (i.e. recordings of handwritten material with audio) **Comment (likes/dislikes) ->**	N/A	1	2	3	4	5
C8. External online resources (e.g. Khan Academy) - (please specify which sites you use) **Comment (likes/dislikes) ->**	N/A	1	2	3	4	5
C9. Facebook or other social media **Comment (likes/dislikes) ->**	N/A	1	2	3	4	5

D1 Please add any additional comments on resources that you currently use or would like to have available outside class.

AUTEC Reference number 14/188

Appendix 3 / Staff Survey – Tablet PCs and STEM Lecture Presentation Methods

VF1e Apr2015 Resp No: ....

Staff Survey – Tablet PCs and STEM Lecture Presentation Methods

This survey asks for your feedback on how you view the effectiveness of the use of Tablet PCs and different lecture presentation modes. **Your participation in this survey is voluntary, as specified in the Research Project Information sheet.**

Instructions: Please answer the following questions in relation to your teaching of a paper, or papers, in which you have used a Tablet PC and which have a ***significant mathematical component*** (i.e. where equations, graphs etc are used to solve problems). Where appropriate, please add comments to elaborate on your answers. You may fill out this form digitally by clicking in answer fields (coloured areas) or by using the pen tool in Revu, or on a paper version.

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1 Please record details of the Paper(s) in which you have been (or expect to be) using the Tablet PC.

Please answer *following questions* in relation to *Paper(s) listed here.*

Paper	Year/Semester Started Use	No. of Sems used	Class Size (approx)

2 For *a mathematics based* Paper in the list above for which you have used the Tablet PC the most (or a group of Papers which share a similar teaching approach), please indicate the frequency with which you typically use each of the following activities in a lecture class. Circle or highlight/**bold** the Paper(s) in **1** above for which your answers will apply. For regularly used activities, also indicate (in the last dotted box) the approximate % of the class time that is typically spent on that activity in a lecture session.

Show slides (PPT)	1 ~Never	2 Seldom	3 Frequently	4 Most sessions	5 (almost) Always	% class time
Introduce new *handwritten* theory	1 ~Never	2 Seldom	3 Frequently	4 Most sessions	5 (almost) Always	% class time
Develop example problems - *handwritten*	1 ~Never	2 Seldom	3 Frequently	4 Most sessions	5 (almost) Always	% class time
Show video/ multimedia	1 ~Never	2 Seldom	3 Frequently	4 Most sessions	5 (almost) Always	% class time
Ask/Answer Questions	1 ~Never	2 Seldom	3 Frequently	4 Most sessions	5 (almost) Always	% class time
Demonstrate Software	1 ~Never	2 Seldom	3 Frequently	4 Most sessions	5 (almost) Always	% class time
Students Do problems ***Individually***	1 ~Never	2 Seldom	3 Frequently	4 Most sessions	5 (almost) Always	% class time
Students Do problems ***In Pairs***	1 ~Never	2 Seldom	3 Frequently	4 Most sessions	5 (almost) Always	% class time
Students Do problems ***In Groups***	1 ~Never	2 Seldom	3 Frequently	4 Most sessions	5 (almost) Always	% class time
Other (specify)	1 ~Never	2 Seldom	3 Frequently	4 Most sessions	5 (almost) Always	% class time
Other (specify)	1 ~Never	2 Seldom	3 Frequently	4 Most sessions	5 (almost) Always	% class time

Page 1 of 8

3 Please rate your perception of the following in-class *presentation* methods.
(Tick the appropriate box)

Rating Scale ->	N/A Not Used/ No opinion	1 Very poor/ Very	2 Poor/ Ineffective	3 Average	4 Good/ effective	5 Very good/ effective
3a Handwritten material on a whiteboard	N/A	1	2	3	4	5
Comments ->						
3b PowerPoint slides displayed via a data-projector (*without* in-class annotation)	N/A	1	2	3	4	5
Comments ->						
3c PowerPoint slides *with live annotation* displayed via a data-projector	N/A	1	2	3	4	5
Comments ->						
3d Handwritten material on a document camera	N/A	1	2	3	4	5
Comments ->						
3e Handwritten material on a Tablet PC (e.g. in OneNote)	N/A	1	2	3	4	5
Comments->						
3f Other computer based material (software demonstration, video etc)	N/A	1	2	3	4	5
Comments->						
3g Other (specify)	N/A	1	2	3	4	5
Comments->						

4 How often do you use the following types of representation in class sessions?
Note: please give separate answers for i) live handwritten and ii) preprepared 'text/print/graphic' form (i.e. *not live* handwritten/drawn). Please tick boxes as appropriate.

4a Equations (math) i) live *handwritten*	N/A	1 Never	2 Seldom	3 Frequently	4 Most sessions	5 (almost) Always
ii) pre-prepared & typed/text	N/A	1 Never	2 Seldom	3 Frequently	4 Most sessions	5 (almost) Always
Comment:						
4b Graphs i) hand drawn *live*	N/A	1 Never	2 Seldom	3 Frequently	4 Most sessions	5 (almost) Always
ii) pre-prepared images	N/A	1 Never	2 Seldom	3 Frequently	4 Most sessions	5 (almost) Always
Comment:						

4c Diagrams

i)hand drawn *live*	N/A	1 Never	2 Seldom	3 Frequently	4 Most sessions	5 (almost) Always
ii) pre-prepared images	N/A	1 Never	2 Seldom	3 Frequently	4 Most sessions	5 (almost) Always

Comment:

4d Other (specify)

i) hand drawn *live*	N/A	1 Never	2 Seldom	3 Frequently	4 Most sessions	5 (almost) Always
ii) pre-prepared images	N/A	1 Never	2 Seldom	3 Frequently	4 Most sessions	5 (almost) Always

Comment:

5 What level of importance do you place on you having the capability to *develop and display* handwritten material in class (i.e access to a whiteboard or writing tablet?	N/A No opinion	1 Definitely not required	2 Limited importance - not essential	3 Some importance as an option	4 Important - necessary	5 Extremely important - vital

Comments (Why?)

6 Please tick boxes to indicate *your expectations* of what *students* should do during class, and indicate *your* view of their typical levels of compliance:

6a Take notes (in any form: typed, audio, handwritten, ..)	N/A No opinion	1 Don't allow	2 Discourage	3 Up to Student	4 Encourage	5 Exhort/ Require
Indicate their general level of compliance ->	N/A	1 ~Never	2 Seldom/ Few	3 Sometimes/ Some	4 Frequently/ Most	5 (almost) Always/ All

Comments ->

6b Take (specifically) *handwritten* notes	N/A No opinion	1 Don't allow	2 Discourage	3 Up to Student	4 Encourage	5 Exhort/ Require
Indicate level of compliance ->	N/A	1 ~Never	2 Seldom/ Few	3 Sometimes/ Some	4 Frequently/ Most	5 (almost) Always/ All

Comments ->

6c Take supplementary notes on copies of PowerPoint Slides made available before class.

N/A	1 (see **Note**)	2	3	4	5 Exhort/
No opinion	**Won't** provide	**Don't** provide	Up to Student	Encourage	Require

Indicate level of compliance ->

N/A	1 (almost)	2	3	4	5 (almost)
No opinion	Never	Seldom/ Few	Sometimes/ Some	Frequently/ Most	Always/ All

Note: (If you won't make slides available beforehand on principle, tick 1; if you currently don't provide, but would consider, tick 2))

6d Please describe any other critical activities that you commonly expect students to do in class.

7 Please tick boxes to indicate your suggested actions for *students* to do *between* class sessions.
(N/A if resource is not made available)

7a Revise ***their own*** notes from *previous* session

N/A	1	2	3	4	5 Exhort/
No opinion	Don't allow	Discourage	Up to Student	Encourage	Require

Indicate students typical level of compliance

N/A	1 (almost)	2	3	4	5 (almost)
No opinion	Never	Seldom/ Few	Sometimes/ Some	Frequently/ Most	Always/ All

Comments ->

7b Review lecturer provided/ specified **text or textbook notes** covering ***previous*** session.

N/A	1	2	3	4	5 Exhort/
No opinion	Don't allow	Discourage	Up to Student	Encourage	Require

Indicate students typical level of compliance

N/A	1 (almost)	2	3	4	5 (almost)
No opinion	Never	Seldom/ Few	Sometimes/ Some	Frequently/ Most	Always/ All

Comments ->

7c Revise lecturer provided ***handwritten*** notes from previous session (e.g online PDF of

N/A	1	2	3	4	5 Exhort/
No opinion	Not provided	Discourage	Up to Student	Encourage	Require

Indicate students typical level of compliance

N/A	1 (almost)	2	3	4	5 (almost)
No opinion	Never	Seldom/ Few	Sometimes/ Some	Frequently/ Most	Always/ All

Describe form of resource (e.g PDF of OneNote pages)

7d Revise ***video*** of previous lecture

N/A	1	2	3	4	5 Exhort/
	Not provided	Discourage	Up to Student	Encourage	Require

Indicate students typical level of compliance

N/A	1 (almost)	2	3	4	5 (almost)
	Never	Seldom/ Few	Sometimes/ Some	Frequently/ Most	Always/ All

Comments ->

7e Revise a ***screencast*** of content from a previous session

N/A	1	2	3 Up to	4	5 Exhort/
	Not provided	Discourage	Student	Encourage	Require

Indicate students typical level of compliance

N/A	1 (almost)	2	3	4	5 (almost)
No opinion	Never	Seldom/ Few	Sometimes/ Some	Frequently/Most	Always/ All

Comments ->

7f	Read textbook or lecturer pre-prepared notes for ***upcoming*** sessions	N/A No opinion	1 Not provided	2 Discourage	3 Up to Student	4 Encourage	5 Exhort/ Require
	Indicate students typical level of compliance	N/A No opinion	1 (almost) Never	2 Seldom/ Few	3 Sometimes/ Some	4 Frequently/ Most	5 (almost) Always/ All
	Comments ->						

7g	Access online screencasts of ***upcoming*** material	N/A No opinion	1 Not provided	2 Discourage	3 Up to Student	4 Encourage	5 Exhort/ Require
	Indicate students typical level of compliance	N/A No opinion	1 (almost) Never	2 Seldom/ Few	3 Sometimes/ Some	4 Frequently/ Most	5 (almost) Always/ All

7h	Access online supplementary material (such as Khan	N/A No opinion	1 Not provided	2 Discourage	3 Up to Student	4 Encourage	5 Exhort
	Indicate students typical level of compliance	N/A No opinion	1 (almost) Never	2 Seldom/ Few	3 Sometimes/ Some	4 Frequently/ Most	5 (almost) Always/ All
	Describe the form of the supplementary resources						

7i	Complete online quizes or online problems	N/A No opinion	1 Not provided	2 Discourage	3 Up to Student	4 Encourage	5 Exhort
	Indicate students typical level of compliance	N/A No opinion	1 (almost) Never	2 Seldom/ Few	3 Sometimes/ Some	4 Frequently/ Most	5 (almost) Always/ All
	Comments ->						

7j	Use software (to solve problems etc)	N/A No opinion	1 Not provided	2 Discourage	3 Up to Student	4 Encourage	5 Exhort/ Require
	Indicate students typical level of compliance	N/A No opinion	1 (almost) Never	2 Seldom/ Few	3 Sometimes/ Some	4 Frequently/ Most	5 (almost) Always/ All
	Comments ->						

7k	Other (please specify)	N/A No opinion	1 Not provided	2 Discourage	3 Up to Student	4 Encourage	5 Exhort/ Require
	Indicate students typical level of compliance	N/A No opinion	1 (almost) Never	2 Seldom/ Few	3 Sometimes/ Some	4 Frequently/ Most	5 (almost) Always/ All
	Comments ->						

8a Please tick the box that best describes how your teaching approach has changed (if at all) in association with the use of a Tablet PC? [If you have not yet started using the Tablet, please answer as to how you *anticipate* changing (or ✓N/A)].

N/A No opinion	No significant changes	Improved delivery presentation, Same basic approach	Some modification of teaching approach	Substantial change in teaching approach	Completely changed teaching approach

Comment:

8b	For which of the following do you use your Tablet PC (tick)?	N/A No opinion	Presenting in a Classroom	Marking of student assignments	Preparation of Screencasts	Annotating documents (e.g. PhD supervision)	Other (describe below)

Comment:

8c	The Tablet PC has replaced the whiteboard for handwriting.	N/A	1 (almost) Never	2 Seldom	3 Sometimes/ Some	4 Frequently/ Mostly	5 (almost) Always

8d	Handwriting on the Tablet PC has replaced PowerPoint for delivering material	N/A No opinion	1 (almost) Never	2 Seldom	3 Sometimes/ Some	4 Frequently/ Mostly	5 (almost) Always

Comment on any other changes in your teaching:

9a	How confident are you in the use of computer technology (in general) ?	N/A No opinion	1 Very difficult	2 Limited confidence	3 Average	4 Confident	5 Very confident

Comments:

9b	How confident are you in the use of the **Tablet PC** in the class environment?	N/A No opinion	1 Very difficult	2 Limited confidence	3 Average	4 Confident	5 Very confident

Comments:

9c	How easy do you find (or expect) a **Tablet PC to be to use** in the class environment?	N/A No opinion	1 Very difficult	1 Somewhat difficult	3 Average/ Manageable	4 Easy	5 Very Easy

Comments:

10 What influenced you to start (or intend to start) using a Tablet PC in your teaching?

My departmental teaching colleagues	N/A No opinion	1 No Influence	2 Small influence	3 Somewhat influenced	4 Strongly Influenced	5 Convincing Influence
Seminar demonstrations	N/A No opinion	1 No Influence	2 Small influence	3 Somewhat influenced	4 Strongly Influenced	5 Convincing Influence
Online Material	N/A No opinion	1 No Influence	2 Small influence	3 Somewhat influenced	4 Strongly Influenced	5 Convincing Influence
Research Papers	N/A No opinion	1 No Influence	1 Small influence	3 Somewhat influenced	4 Strongly Influenced	5 Convincing Influence
Other(Specify):	N/A No opinion	1 No Influence	2 Small influence	3 Somewhat influenced	4 Strongly Influenced	5 Convincing Influence

Comments ->

		N/A	1	2	3	4	5
11	How frequently have you experienced significant technical problems with the TabletPC in class?	N/A	1 Frequently (over 50%)	2 Often (~ 20%)	3 On Occasion	4 Very Infrequently (<~5%)	5 Virtually never

Please indicate the number of Semesters (if any) in which you have used different types of Tablet PC.

HP2760P	Lenovo Helix	Surface Pro 3	Other (specify)

Comment on devices:

As applicable, list the (most common) problems and indicate their frequency:

11a		1 Frequently (over 50%)	2 Often (~ 20%)	3 On Occasion	4 Very Infrequently	5 ~ Never
11b		1 Frequently	2 Often (~ 20%)	3 On Occasion	4 Very Infrequently	5 ~ Never
11c		1 Frequently	2 Often (~ 20%)	3 On Occasion	4 Very Infrequently	5 ~ Never
11e		1 Frequently	2 Often (~ 20%)	3 On Occasion	4 Very Infrequently	5 ~ Never
11f		1 Frequently	2 Often (~ 20%)	3 On Occasion	4 Very Infrequently	5 ~ Never

12 How would you rate the value of (or your preferences for) the following as ways of learning/improving techniques for *your* use of a Tablet PC?

12a	One-on-one training	N/A No opinion	1 Not wanted	2 Of limited use	3 Useful	4 Very useful	5 Essential
12b	Workshop sharing sessions with other staff	N/A No opinion	1 Not wanted	2 Of limited use	3 Useful	4 Very useful	5 Essential
12c	Tips given by departmental teaching colleagues	N/A No opinion	1 Not wanted	2 Of limited use	3 Useful	4 Very useful	5 Essential
12d	Independent access to AUT OneNote shared notebook	N/A No opinion	1 Not wanted	2 Of limited use	3 Useful	4 Very useful	5 Essential
12e	Specific Online resouces (e.g. Lynda.com)	N/A No opinion	1 Not wanted	2 Of limited use	3 Useful	4 Very useful	5 Essential
12f	General Online resouces (Google)	N/A No opinion	1 Not wanted	2 Of limited use	3 Useful	4 Very useful	5 Essential
12g	Other(Specify):	N/A No opinion	1 Not wanted	2 Of limited use	3 Useful	4 Very useful	5 Essential
12h	Other(Specify):	N/A No opinion	1 Not wanted	2 Of limited use	3 Useful	4 Very useful	5 Essential

13 What feedback (formal or informal) have you received from your students regarding the use of Tablet PCs? Please summarise their responses.

Please continue on a separate sheet if necessary

14 What do you see as the main benefits of using a Tablet PC?(Please give reasons for your answer)

Please continue on a separate sheet if necessary

15 What do you see as the main disadvantages of using a Tablet PC?
(Please give reasons for your answer)

Please continue on a separate sheet if necessary

Please enter your contact details if you are happy to be contacted ->

Name:

Phone:

Email: