

I SEE WHAT YOU YOU'RE DOING: STUDENT VIEWS ON LECTURER USE OF TABLET PCS IN THE CLASSROOM

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Abstract:

A fundamental component in the teaching of STEM subjects, particularly those involving mathematical processes, has traditionally been a classroom session with a teacher modelling theory and problem solving using a chalkboard or white board.

While there has been generic criticism of this style of teaching, it has been strongly defended by practitioners in mathematical disciplines. This use of a dynamic handwritten approach has been linked with the use of boards as the necessary classroom technology.

This paper arises from a study that surveyed students studying mathematically-intensive engineering subjects at a range of undergraduate levels in a university environment. It reports on student perceptions of the effectiveness of board and alternative technologies within existing classroom contexts, and in particular, views on the use of pen-enabled Tablet PCs (penTPCs). While not primarily examining the appropriateness of traditional classroom pedagogical approaches, the analysis does suggest potential directions for change.

Students in the study revealed a strong preference for the use of penTPCs as a delivery technology. The high visibility of handwritten material delivered by this technology, along with support for inclusion of other digital outputs and post-class access to material, were key factors influencing student preferences.

1 INTRODUCTION

This paper is concerned with the teacher use of technology in the tertiary campus environment (lecture theatre and classroom) for the presentation of mathematically based material. Traditional delivery modes in these environments have involved the use of handwritten board technology in association with what has 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, 2014).

These criticisms have generally been made without consideration of the disciplines involved. Fox and Artemeva (2011) looked specifically at the nature of the mathematics lecture, and used the term 'chalk talk' (i.e. without the 'and') to denote a characteristic approach in mathematical disciplines. They determined that *in the context of mathematics education* chalk talk can be 'pedagogically interactive, meaningful, and engaging', even when it is essentially transmissive. Indeed, Bates (2014) acknowledges that there may be some value in the transmissive lecture where it explicitly models expert thinking. This is the position taken by (McKeachie & Svinicki, 2013) –and precisely the role that Greiffenhagen (2008) advocates in claiming: "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". Expert modelling is also a key function of the mathematics lecture identified by (Bergsten, 2007). In practice the chalk talk lecture will often fit the description of interactive as defined by Bates (2014) as "where at least 25% of the time is taken up with questions and discussion from students and responses from the lecturer to points raised by students".

The primary purpose of this paper is however not to critique the merits of this form of teaching, but to examine the use of different technologies that may be used in support of any approach that requires the presentation of handwritten material in a classroom environment.

Where they have had control over their own teaching spaces, university teachers of mathematics disciplines have frequently retained writing boards as their preferred technology (Artemeva & Fox, 2011, p.357; Greiffenhagen, in press). The centralisation of responsibility for the management of teaching rooms in many institutions has encouraged the development of standardised generic rooms incorporating a common technology platform. The use of a centralised timetabling system may then be used to allocate these generic spaces so as to achieve efficiency in occupation rates, but often without at the expense of meeting the particular preferences of individual disciplines. For example, Greiffenhagen (in press) 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'. High level institutional initiatives for architectural, technical and pedagogical innovation have also promoted developments that may conflict with traditional expectations (Jamieson et al., 2000; Jamieson, 2007; Neary & Saunders, 2011).

The blackboard/chalkboard became a standard classroom tool starting in the 1800s, but was supplanted in most classrooms by the whiteboard (or dry erase board) beginning in the 1980s. The overhead projector (OHP) began to supplement writing boards from around the 1950s (Krause, 2000; Kidwell et al., 2008), but in university environments the OHP has generally been superseded by digital devices.

The data projector, connected to a standard desktop computer, has become a standard technology configuration in most university teaching spaces (at least in the study institution) for the display of digitally sourced material. The standard computer, with only keyboard and mouse, does not support handwritten inputs, so the use of software such as PowerPoint to display slides of prepared material has become common.

The ubiquitousness of the 'chalk talk' approach in mathematical classrooms (and explicit use of 'chalk' in the term) might be taken to imply that the use of an actual chalkboard (or whiteboard) is fundamental to the approach. However, it is not the use of a particular form of the writing surface that is the critical element of the chalk talk approach, but the elements of live development and pacing that handwritten material affords. There are now alternatives to board technologies that can support these elements (Epper & Bates, 2001).

The document camera, with data projector, has become the default (and sometimes only) option for the display of handwritten material in many university lecture theatres (Brooks-Young, 2007). More recently the development of digitisers, either within stand-alone monitors or incorporated in devices such as the Tablet PC, has provided another option for the projection of live handwritten material.

While lecturers will have their own personal preferences for delivery technologies, formed by their prior experiences, it is important that the views of students - of what works best for them - are also used to guide developments. For students now coming to university, the online digital environment plays a central part in the way they experience their world. To be effective, the university needs to develop an environment that meets the needs of both learners and teachers. This paper reports a student viewpoint.

2 STUDY APPROACH

The participants in the study were students attending class sessions in which the lecturer was using a penTPC in teaching mathematically-intensive engineering subjects in a university environment. While the student survey was drawn from what was essentially a convenience sample of six class sessions (selected based on timetabling and lecturer availability), it should be noted that their ratings would be based on the range of their experiences (across class sizes, rooms, subjects and lecturers), not just on the experiences in that one session (or class) in which they were surveyed.

The class sessions surveyed included a range of levels, from first year to 3rd year undergraduate level, and a range of subjects, including both general engineering mathematics and more specialized

(mechanical engineering design) discipline areas. 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 students in the classes surveyed had had experience across a range of delivery technologies (covering traditional whiteboards, 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 that technology.

The students were invited by a researcher, who was not teaching the session, to complete an optional, anonymous paper based survey at the conclusion of a class session. 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 had the opportunity 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 student *their perception* of the effectiveness of five different classroom technologies: basic PowerPoint; PowerPoint with live handwritten annotations; whiteboards; pen-enabled Tablet PCs used to develop handwritten notes; 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). In addition, students were asked to comment in a free text field on what they liked or disliked about each technology mode.

This survey was conducted as part of an ongoing design research study, which is focused on developing guidelines for the introduction and effective use of penTPC technology (with potential generalisation to other technologies) in a university environment.

3 STATISTICAL ANALYSIS

This section provides a quantitative statistical analysis of the student survey responses to the question asking their perceptions of the effectiveness of different modes of class delivery. While a range of statistical techniques are applied, and results given in this section, it is critical that these numerical results are interpreted in context of the study, and in conjunction with other qualitative data (such as student comments). The fuller interpretation of results is therefore provided in the discussion section following this.

If the population of interest is taken as being the students *attending* the lecture sessions, the very high rates of return of surveys forms means the results might be interpreted directly as good indicators of population statistics. Taking a more conservative approach, and regarding the results as being a sample coming from a large population, the results will be shown to still confirm meaningful and significant differences between different delivery modes using a range of tests.

The appropriateness of using quantitative interval-scale measures and analysis for this type of ordinal data has been a subject of ongoing debate (Baker, Hardyck, & Petrinovich, 1966; Landry, 2015; Marcus-Roberts & Roberts, 1987). The initial analysis here uses ordinal techniques, with a focus on percentages as a measure, as advocated by Knapp (2015).

Table 1 provides a summary of student ratings of effectiveness of the different modes, showing percentages and response counts for ratings within each mode. Not all students rated all modes, hence differences in totals. For ease of referencing (and for later analysis), a numerical label was later assigned to each category, with -2 as Very Poor/Very Ineffective, -1 as Poor/Ineffective, 0 as Average, 1 as Good/Effective and 2 as Very Good/Very Effective). While still applying an ordinal treatment, in subsequent discussion the combination of Good/Effective and Very Good/Very Effective categories will be collectively described as being a 'Positive' rating, and similarly, the categories Very Poor/Very Ineffective and Poor/Ineffective as being a 'Negative' rating).

A Chi-Square analysis on response numbers in Table 1 confirms that there is a statistically significant ($\chi^2 = 407.8$, $df = 16$, critical value $99 = 5.8$, $p\text{-value} < 2 \times 10^{-16}$) difference between the distributions of the different modes. The nature of this difference is now examined.

	PowerPoint on DPSc (PPT)		Document Camera on DPSc (DocCam)		Whiteboard (WhiteBd)		penTPC + PPT with Annotation on DPSc (TPC_PPTA)		penTPC + OneNote on DPSc (TPC_ON)	
	n	%	n	%	n	%	n	%	n	%
2 Very Good/Very Effective	34	7.7%	49	12.7%	115	26.1%	116	25.9%	195	41.3%
1 Good/Effective	103	23.2%	108	28.0%	153	34.7%	211	47.1%	203	43.0%
0 Average	193	43.5%	143	37.0%	111	25.5%	101	22.5%	54	11.4%
-1 Poor/Ineffective	81	18.2%	53	13.5%	43	9.8%	14	3.1%	8	1.7%
-2 Very Poor/Very Ineffective	33	7.4%	33	8.5%	19	4.3%	6	1.3%	12	2.5%
Total	444	100%	386	100%	441	100%	448	100%	466	100%

Table 1: Ratings of Effectiveness (1-5) by delivery mode. Note that totals differ for each mode as not all questions were answered all students.

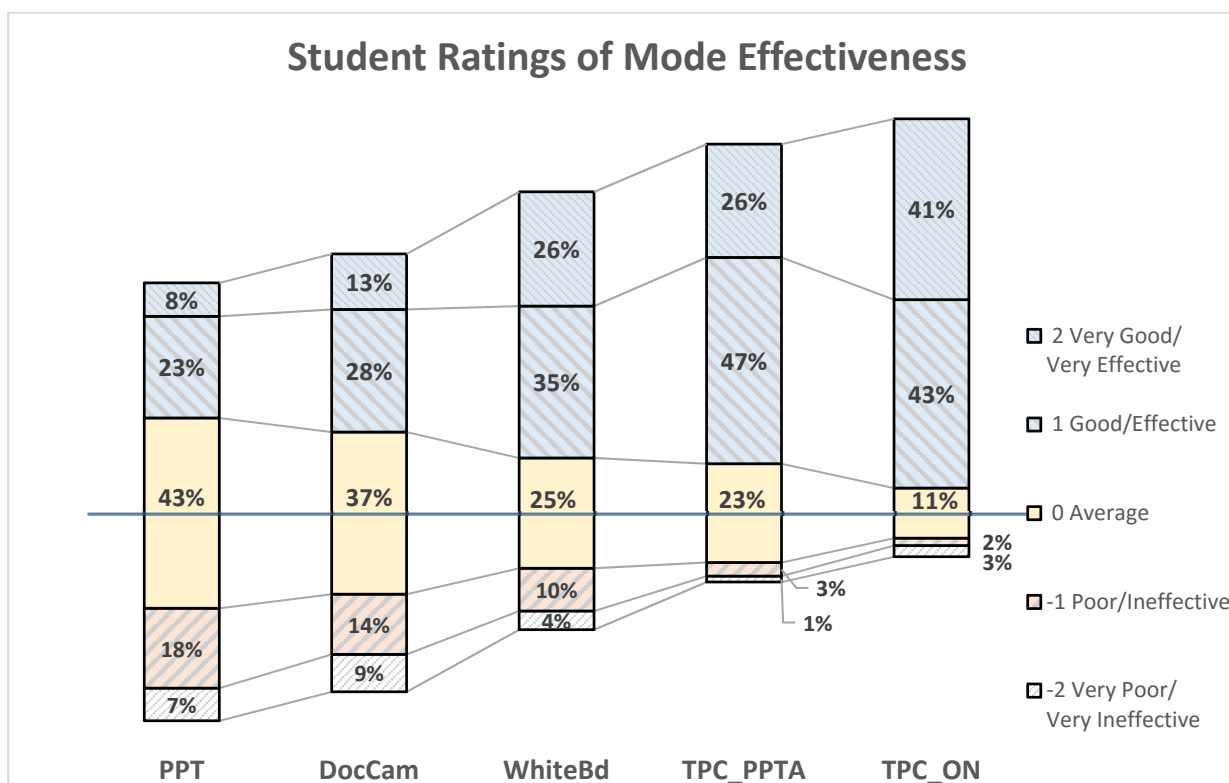


Fig 1: Student Ratings of Mode Effectiveness.

Bars divisions show the breakdown of ratings for each technology mode as percentages. The position of each bar is adjusted vertically to align the midpoints of the 'Average' rating categories. Note: Not all % totals add to 100 due to rounding.

The data in Table 1 is displayed in comparative stacked percentage column charts in Fig 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 chart in Fig 1 shows an increasing preference in order from (standard) PowerPoint, to Document Camera, Whiteboard, and to the pen enabled Tablet PC modes, using PowerPoint with Annotation, and then with OneNote software (the most preferred option). The percentages of students who assign a Positive rating and percentages who assign a Negative rating are tabulated Table 2. These values may be visualised in Fig 1 as the top 2 segments and bottom 2 segments, respectively, of each bar.

Using the Positive measure in Table 2, the use of the penTPC with OneNote is again judged to be best, with 84% of respondents assigning rating of +1 or +2. The use of the penTPC to annotate *within* PowerPoint was judged next most effective, with 73% assigning a Positive rating. The whiteboard was judged third most effective overall, with a 60% Positive rating. The document camera was judged fourth most effective, with a 41% Positive rating. The use of standard PowerPoint (without annotations) was judged the least effective mode, with 31% assigning a Positive rating. Standard PowerPoint is the only mode that does not incorporate live handwritten material within the class session.

	PowerPoint on DPSc (PPT)		Document Camera on DPSc (DocCam)		Whiteboard (WhiteBd)		penTPC + PPT with Annotation on DPSc (TPC_PPTA)		penTPC + OneNote on DPSc (TPC_ON)	
	n	%	n	%	n	%	n	%	n	%
'Positive' Rating (1 Effective/ 2 Very Effective)	137	31.1%	157	40.7%	268	60.2%	327	72.7%	398	84.1%
'Negative' Rating (-1 Ineffective/ -2 Very Ineffective)	114	25.9%	86	22.4%	62	14.3%	20	4.6%	20	4.3%
Total Responses (for the mode)	444		386		441		448		472	

Table 2: Summary Ratings - % of students rating modes 1&2 and % of students rating -1&-2, by delivery mode. Not all students provided a rating for every mode.

As advocated by Landry (2015) for application to ordinal data, the procedure developed by Marascuilo (Marascuilo, 1966), and as described in the online NIST/SEMATECH e-Handbook of Statistical Methods (2013), was used to compare differences in ratings. In applying this procedure, a difference between mode proportions is judged significant if the observed difference exceeds a calculated critical value (at the selected level of significance).

The observed differences between the proportion of students assigning a positive rating to modes are shown as a pairwise comparison in Table 3, together with critical values at both 95% and 99% levels. The analysis showed that differences in all pairwise comparisons of the modes are significant at a 99% confidence level, except for the difference between PowerPoint and Document Camera modes, which is *just* significant at a 95% level.

Having established that the differences between modes are statistically significant, the nature and extent of the differences will be investigated.

	DocCam	WhiteBd	PPTAnno	TabPC
PPT	0.096 .095 0.121	0.291 0.095 0.117	0.416 0.091 0.111	0.530 0.083 0.101
DocCam		0.195 0.098 0.123	0.320 0.094 0.119	0.434 0.086 0.010
WhiteBd			0.125 0.093 0.114	0.239 0.086 0.109
PPTAnno				0.114 0.081 0.098

Table Key:		Not Significant
Observed Difference		Significant 95%
Critical Value (95%)	Critical Value (99%)	Significant 99%

Table 3: Marasculio Procedure Analysis: Pairwise comparisons of modes, using % of students assigning a positive rating a mode ‘above average’. Observed values that exceed the calculated critical value (at the given CI) are regarded as significant, with the and are shaded in the table.

3.1 Effect Size

Attention is now given to the important issue (Coe, 2002) of effect size i.e. whether the size of the differences are large enough to be noticeable and meaningful in the context of the study. In this study, effect size is concerned whether the differences between ratings of alternative technologies are meaningfully large enough to justify recommending the use of one technology over another.

A recommended measure of effect size for ordinal data such as this is Cliff’s Delta (Cliff, 1993), also referred to as the “*dominance measure of effect size (DM)*” (Grissom & Kim, 2005, p. 107). Estimated by the dominance statistic *ds*, it evaluates effect size in terms of the proportion of overlap between two sample distributions (Grissom & Kim, 2005). A *ds* value of 0 indicates the distributions are coincident (i.e. there is no effect in using different approaches), and a value of 1 (or -1) indicates a complete separation between the distributions being compared (i.e. a strong effect).

The calculations for Cliff’s delta (and other statistics) were carried out using Rogmann’s Ordinal Dominance Statistics (ORDDOM) package (2013) for R statistical software. A paired case analysis was used i.e. comparing two delivery modes by calculating the proportion of cases for which an individual student’s rating for one mode exceeded their rating for the other, minus the proportion of cases with the reverse rating order). This use of a paired data approach means effects of potential different interpretations by students of the rating question scale are minimised; the measure records for each student whether they have a *preference* for one mode over another. Results are displayed in Table 4.

While the *ds* measure may be interpreted directly in comparisons, Cohen’s *d* (1988) is more commonly used to interpret the effect size of interventions. While Cohen’s *d* is applicable to normally distributed interval scale variable, the *ds* measure may be converted to provide an estimate of an equivalent Cohen’s *d* statistic (i.e. estimating the standardised mean difference for which normal distributions would show an equivalent overlap to the ordinal analysis) (Meissel, 2014, p. 46). Rogmann’s ORDDOM package for R (2013) also provides this equivalent measure, which are shown with the *ds* values in Table 4.

Cohen produced a set of rough criteria for judging effect sizes, widely referenced by other authors (Coe, 2002; Grissom & Kim, 2005), that rated an effect size *d* of ≤ 0.2 as ‘small’, 0.5 (quoted as a point value) as a ‘medium’ effect, and ≥ 0.8 as a ‘large’ effect. Hattie (2005, 2013), in a meta-analysis that evaluated the comparative worth of a wide range of different educational interventions, suggested an effect size of Cohen’s *d* ≥ 0.4 as level indicating intervention as being worthwhile. Table 4 shows the TabPC_OneN mode having Cohen’s *d* of ≥ 0.4 against all other modes, except in comparison with the other TabletPC mode (TabPC_PPTA), where the effect is 0.27. The standard, unannotated PowerPoint mode is noticeably worse than all other modes.

	DocCam	WhiteBd	TabPC_PPTA	TabPC_OneN
PPT	$ds=0.10^*$ $d=0.13$	$ds =0.31^{***}$ $p\approx 0$ $d=0.45$	$ds =0.56^{***}$ $d=1.00$	$ds =0.60^{***}$ $d=1.14$
DocCam		$ds =0.23^{***}$ $d=0.26$	$ds =0.38^{***}$ $d=0.41$	$ds =0.55^{***}$ $d=0.55$
WhiteBd			$ds =0.12^{***}$ $d=0.15$	$ds =0.30^{***}$ $d=0.44$
TabPC_PPTA				$ds =0.20^{***}$ $d=0.27$

Table 4: Effect Size: Cliffs Delta and Cohen's d

Cell Key: ds = dominance statistic, or Cliff's delta; *** = $p < .001$; ** = $p < .01$; * = $p < .05$
 d = Estimate of Cohen's d based on paired ordinal analysis and
(in brackets) treating data as being on an interval scale.
 n = number of samples for paired comparisons

Effect Size shading key	small ≤ 0.2	$0.2 \leq$ medium-small < 0.4	≤ 0.4 medium < 0.8	Large ≥ 0.8
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The preceding analysis determined statistics and effect sizes using ordinal methods deemed appropriate for such data by conservative statistical theorists (Knapp, 1990, 2015; Marcus-Roberts & Roberts, 1987). However, there are also strong arguments for potential value of using parametric analysis where it can generate useful measures that may be easily interpreted and communicated *in the context of the study* (Velleman & Wilkinson, 1993). As with the ordinal analysis, *any* calculated summary statistic can be misleading and needs to be considered in conjunction with the nature of the data and the questions being asked. Graphic visualisations, such as in Fig 1, can providing insights into the likely influences of scales on measures.

A primary source of objection to use of parametric analysis with ordinal data is the potential effect on the generated statistics of assigning what may be argued are arbitrary intervals to the ordinal data. However, it is considered that applying a consistent value scale across evaluations of all the different technology modes here allows for useful comparisons of those modes *given an understanding of the assumptions and implications of that scale allocation*.

Using an interval scale, of -2, -1, 0, 1, 2 provides for simplicity in calculation and in interpretation of statistics such as effect size. The mean rating for each mode can be used as a summary indicator of mode effectiveness. These scale assigns weightings such that shifts of more than one category e.g. a shift from 'average' to 'very good' will have twice the weight of a shift from 'average' to 'good'. This is regarded as suitable for use here in making judgements in quality improvements where a goal of 'very good' may be emphasised (and outcomes of 'very poor' are to be strongly avoided). It may be noted that in determining Cliff's delta in the ordinal analysis, there are also implicit assumptions in the relative worth of movements between categories; any improvement of one *or more* categories is scored as a +1, no change as a 0, and any drop in one *or more* categories as a -1. Using this integer interval scale, the average ratings for each mode, standard deviation, sample size, and 95% confidence interval are shown in Table 5.

The means for each mode, with a 95% confidence interval are displayed in the chart in Fig 2.

	PPT	DocCam	WhiteBd	TabPC_PPTA	TabPC_OneN
Mean \bar{x}	0.05	0.23	0.68	0.93	1.19
s	1.0	1.1	1.1	0.85	0.89
n	444	386	441	448	472
Mean C.I. (95%)	(-0.4 – 0.15)	(0.12-0.34)	(0.58-0.79)	(0.85-1.01)	(1.11-1.27)

Table 5. Parametric Summary Statistics for Modes

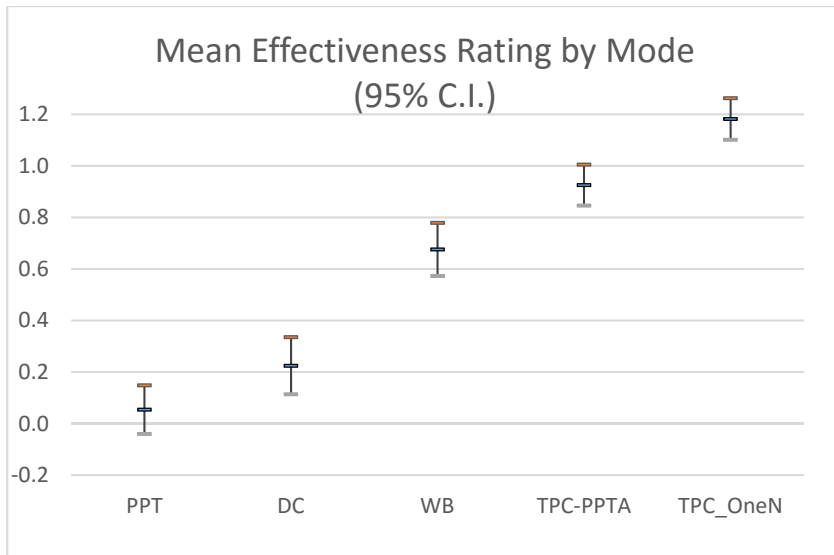


Fig x: Mean Effectiveness Rating by Mode
(Note: Calculated by assigning values -2, -1, 0, 1, 2 to categories)

Differences between the average ratings for the modes provide a simple comparative measure of effect size, and are shown in Table 6, denoted as '*dm*', measure in units of 'number of categories' of shift. Also tabulated (denoted as '*md*') are the differences paired by student (i.e. for each student who has given a rating for both the modes in question, recording the difference between mode ratings, and averaging these differences over all students). There is little different from those obtained from the overall mean comparison.

We may also interpret these values as a numerical approximation to a Standardized Mean Difference (SMD) or Cohen's *d* value. This value is calculated by dividing the mean difference by an appropriate standard deviation, or SD. While recognising that there are assumptions, including normality, that are not met by this data, a simple approximation, taking 1 for the SD (and the overall underlying pooled standard deviation here is 0.99), suggests the values of the differences in mean (*dm* or *md*) in Table 6 could be interpreted as Cohen's *d* values directly.

The table reveals a similar relationship and effect size to that shown in the ordinal analysis. The Tablet PC – OneNote mode is rated best (mean of 1.19, with an effect size over PowerPoint of more than one category, and one-half a category improvement over Whiteboard.

	DocCam	WhiteBd	TabPC_PPTA	TabPC_OneN
PPT	<i>dm</i> = 0.17 <i>md</i> = 0.2 $n_d=369$	<i>dm</i> = 0.62 <i>md</i> = 0.6 $n_d=369$	<i>dm</i> = 0.87 <i>md</i> = 0.9 $n_d=428$	<i>dm</i> = 1.13 <i>md</i> = 1.1 $n_d=438$
DocCam		<i>dm</i> = 0.44 <i>md</i> = 0.4 $n_d=373$	<i>dm</i> = 0.70 <i>md</i> = 0.7 $n_d=368$	<i>dm</i> = 0.96 <i>md</i> = 1.0 $n_d=382$
WhiteBd			<i>dm</i> = 0.26 <i>md</i> = 0.2 $n_d=423$	<i>dm</i> = 0.51 <i>md</i> = 0.5 $n_d=434$
TabPC_PPTA				<i>dm</i> = 0.26 <i>md</i> = 0.3 $n_d=442$

Table 6. Differences between means (*dm*) and mean differences (*md*) between modes, measured in units of 'category shift'. These differences may also be taken as indicators of effect size. n_d = sample size for paired difference (not all students responded to every question)

4 QUALITATIVE ANALYSIS AND DISCUSSION

A range of different metrics consistently produced a rating order, from worst to best of:

PowerPoint <

< Document Camera

<< Whiteboard

<< Tablet PC with PPT and Annotations

<< Tablet PC and OneNote)

Most differences between modes were evaluated as statistically significant and with meaningfully large effect sizes. The use of the Tablet PC was particularly favoured over other modes.

As well as questions requiring judgments on the perceived effectiveness of delivery modes, students were also invited to provide comments specifically about what they liked and/or disliked about each mode. While statistics developed in previous sections give a broad indication of the relative merits and size of effects, student comments about the different modes provide an understanding of reasons behind these ratings. The following sections provide samples of student comments, with a summary and analysis of critical factors that were identified. Student comments (in italics) are quoted verbatim.

4.1 PowerPoint

Students in all sessions consistently rated the use of basic PowerPoint with prepared slides as the least effective mode. There were 82 comments on this mode. There were some positive comments:

clear and structural ; The advantage of this is that the information is layed out nicely;

however, the majority of the comments were negative:

Lack of engagement; not interactive enough and too easy to stop paying attention; Useful if you miss a lecture but boring in class; Flicking through powerpoints [sic] 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; good for (some subjects) but not for maths; do more example calculations regarding topic on slide; calculations [needed to] get info across; unless used in conjunction with other methods, 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, & Salvendy, 2009). The students in the study are quite clear that basic PowerPoint does not meet their needs for a step-by-step exposition of procedural developments within mathematical disciplines. The student comments reinforce the view previously expressed, that the presentation technology used for traditional lectures in mathematical disciplines needs the capability to allow the lecturer “to dynamically demonstrate the reasoning processes underlying mathematical problem solving” (Maclaren, 2014). Students value the use of traditional handwritten approaches, such as the ‘chalk talk’ approach described by Fox and Artemeva (2011), that restrict the pace of presentation of material.

The superficially conflicting comments that “slides can sometimes carry too much detail” and also that they can “sometimes have too little detail” can be reconciled by consideration of the type of material and the pace of presentation; if the lecturer is modelling expert thinking and developing complex procedural technique then detail of the steps involved, presented at a slow pace, is essential. If factual information is presented at high density and rapidity (e.g. flicking through slides containing large amounts of text), the student will have little time to absorb details. However reducing textual information to bullet points can remove essential context (Tufte, 2003). As one student notes, reading information is something they can do outside class - and there are arguably better formats than standard PowerPoint for doing that.

4.2 The Document Camera

The use of a handwritten approach appears to be regarded by students (and staff) as an essential component in the of teaching mathematical disciplines in the classroom. A range of non-board based technologies that support such an approach have been developed over the years, including the overhead projector (OHP) and the document camera (Brooks-Young, 2007; Krause, 2000). While the OHP has been retired in many institutions (including that of the study), the document camera has become a standard feature in many larger lecture rooms (although not in smaller classrooms) within the university in the study.

Students rate the Document Camera it as the least effective of the handwritten modes and only slightly more effective than basic PowerPoint. A sample of comments suggest the reason:

hand is always in the way and the camera is never in focus; out of focus; 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.

Achieving a clear focus is a critical issue, with 24 (out of 56) specific comments on this issue. While there may be issues particular to the models of document camera installed in the study institution, there are factors inherent in the technology that are generic to all such devices: when in use the hand will be in camera and at times may obscure, and distract from, the written material; the visible writing area is generally limited and requires frequent physical rearrangement of the writing surface (usually paper) with the loss to view of previously written material; and inclusion of other digital material may be constrained.

As with all handwritten approaches, a particular lecturer's technique and handwriting capability in the specific environment may vary considerably. While there may be situations where the document camera has particular uses (e.g. in projecting views of physical artefacts), in this study environment at least, there are alternatives that students consider more effective.

4.3 Whiteboard

The whiteboard is a traditional technology familiar to both students and staff for which usage approaches have been refined over time. It has become a standard technology for the classroom teaching of mathematical disciplines (Fox & Artemeva, 2011). The whiteboard replaced chalk boards in the study university many years previously. Student comments on the use of the whiteboard include:

It keeps the pace of the lecture reasonable and not too fast; 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; It keeps the pace of the lecture reasonable and not too fast

These comments confirm the factor identified previously: the importance students place on a handwritten approach with its influence on pace. For some it was also identified as an old (but good) approach with a comfortable familiarity:

prefer old fashioned writing on the board; I am all old school ... I grew up [with] writing on boards so I feel most comfortable with it;

However, as for the document camera, the largest number of comments (36 out of 115 comments) relate directly to the issue of visibility and readability. A sample of these are:

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; can be hard to read from the back/distance; writing is often too small; difficult to see from the back; cannot see whiteboard; Very hard to read

Some comments relate specifically to the nature of the pens:

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; I like it however the pens are often light or thin;

Lighting is also mentioned as an issue:

Not enough lighting in lecture rooms.

Legibility of handwriting is again an issue (and mentioned across all modes where it is used):

Dependent on the handwriting; Lecturers need to go back and learn how to write neatly;

As student comments show, visibility issues are particularly related to viewing in larger rooms, from the back or from a side of the room. Detailed recommendations concerning the visibility of material from a distance have been produced in relation to signage and projection of visual displays (Association for Audiovisual and Educational Technology Management, 2015; Cai & Green, 2009; Zwahlen, Sunkara, & Schnell, 1995). Factors addressed include the dimensions of the displayed elements (particularly element height and the width of the strokes forming the elements), distance from the material, viewing angles, illuminance, contrast between text elements and background, and the use of a positive contrast (e.g. light text on dark background) or negative (light text on dark background).

An obviously critical factor in visibility is text size (i.e. element height) in relation to viewer distance from the material. Recommendations for teachers writing on a board are often very general, as in “write large enough” (Newbury, 2014), or not related to viewing distance, as in:

Even on a flip-chart, aim to have the body of lower-case letters, (the "x" height) of about 5 cm". (Atherton, 2013).

The Federal Aviation Administration (FAA) provides recommendations for signage (“Human Factors Awareness Course,” n.d.) that are specifically defined in relation to distance, suggesting that for general readability textual elements should subtend a *minimum* visual angle of 20 minutes of arc for the viewer. This guide is used to calculate the recommended minimum element sizes for the different reading distances listed in Table 7. In the absence of any specific guidelines for the display of mathematical equations, these recommendations are taken to apply to the smallest common elements in mathematical expressions, such as indices or integral limits (see for example Fig. 3). On this basis, standard basic algebraic elements, such as the mathematical variable ‘x’, would need to be around twice this height. In a medium-large room, with a maximum viewer distance of 15m, this would require an x (or ω) to be written at a minimum height of 18cm. An expression such as in Fig 3 to be required to be more than 40cm in height, which would limit a typical classroom board (with a height of 90 - 120cm) to 2 - 3 lines of such working. In larger rooms, writing “large enough” becomes a practical limitation in the use of whiteboards.

$$X(j\omega) = \left(\frac{e^{j(\omega+2\pi)t} e^{-\lambda t}}{-\lambda + j(\omega+2\pi)} \right) \Big|_0^{+\infty} + \left(\frac{e^{-j(\omega+2\pi)t} e^{-\lambda t}}{-\lambda - j(\omega+2\pi)} \right) \Big|_0^{+\infty}$$

Fig 3: Example of Mathematical expression with multiple elements (So, 2012)

Maximum viewer Distance from Board	Minimum element size*	Minimum Size of x or ω
5 m	3 cm	6 cm
10 m	6 cm	12 cm
15 m	9 cm	18 cm
20 m	12 cm	24 cm

*based on subtending a minimum visual angle of approx. 20 minutes

Table 7: Viewing Distances and Element size

As well as element size, the issue of stroke width is important for legibility, and was identified in student comments ("*pens are often light or thin*"). When using marker pens on a whiteboard, the stroke width does not scale with size of symbol element, and writing 'larger' will not improve this factor. Effective illumination of a whiteboard is also an issue, especially where a whiteboard is to be used in conjunction with a data projector with conflicting lighting requirements. Advocates for traditional chalkboards may argue that the (generally) wider stroke of chalk and the positive contrast of white chalk on a dark/black board provides better readability; however the environmental issues with chalk dust, for people and electronic devices (Majumdar & William, 2009; Merrill, 1992, p. 237) mean that in most institutions it is unlikely to be considered as a viable option to be reintroduced.

The issue of board visibility is not just limited to larger (tiered) lecture theatres; even with a medium size class, the layout of a standard classrooms can result in some students being at distance such that reading becomes difficult. Portions of the board may be obscured by students in front, given the necessity to mount the whiteboard at a writeable height. Recommendations for data projection screens and seating also recommend the minimum angle of 45 degrees between the display wall and viewer, measured from the furthest edge of the screen (Association for Audiovisual and Educational Technology Management, 2015, p. 17). If whiteboards are extended towards the edge of rooms, seats that provide acceptable viewing angles for centralised screens may not be suitable for reading material on a board at the far side of a room. The issue of the lecturer's body blocking the board while writing, that has been noted in previous reports (Maclaren, 2014), can also exacerbated for seats at the edges of rooms.

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 will have boards that are able to be raised after having been written on, but they are not available in the study university. While vertically moveable boards allow a larger amount of material to become or remain visible after writing and before erasure, they do not address the issues 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 towards use of digital modes. In larger lecture theatres, writing size for readability makes standard board use unviable, and *requires* technological intervention.

4.4 The Pen-enabled Tablet PC with PowerPoint and Handwritten Annotations

A potential digital alternative to the traditional whiteboard is the pen-enabled Tablet PC (penTPC) used in conjunction with a Data Projector and associated screen (Maclaren, 2014). This technology provides a handwriting capability in conjunction with image scaling to suit different environments.

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 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 different 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 "PowerPoint slides with live annotation on (a) data-projector as the second most effective mode, as more effective than 'whiteboard' mode and less effective than the use of the penTPC with OneNote. Student comments on the use of annotation with PowerPoint include:

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; clarification; 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; Depends on subject as long as the updated slides are available for download; good if saved online with notes; Handy if you miss some notes you can look back over it

Student comments indicate that the higher rating given for this mode over standard PowerPoint may be attributed to the reintroduction of a handwritten mode. Rating this higher than whiteboard mode may be attributed to enhancements in visibility. Unsurprisingly, students wanted class sessions to include *live development* of mathematical processes in a format that was *clearly visible*.

4.5 penTPC with OneNote (TPC_ON mode)

Microsoft OneNote has become a standard software for use with Tablet PCs and a data projector as a digital whiteboard replacement (Maclaren, 2014). It provides 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, text and images to be delivered in conjunction with other software and video.

Reasons for the positive student response to the use of this mode are revealed in the following sample of student comments, grouped by theme:

Very effective; Way better than whiteboard; 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 [sic];

These comments again illustrate an obvious point: students need to be able to clearly see the material being presented, and as discussed, whiteboards do not satisfy this requirement in all rooms.

Again, students want to see live development of the steps involved in mathematical procedural thinking.

Oenote way best, as I could understand steps and method; easily accessible notes online and step by step process helps with learning

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

Can bring in figures and tables into notes.

Oviatt (2013) stresses the importance of using interfaces that support "active expression of non-linguistic representations, including diagrams, symbols, numbers, and informal marks". Singer and Smith (2013) 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. 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 hand written board technologies. While many smaller classrooms are equipped with both data projection screens and whiteboards in some form, there are often conflicting requirements in both placement and lighting that can make use of the two modes together less satisfactory.

Another important theme that appears along with lecturer note *creating*, is that of student notetaking:

Good because notes can be uploaded; Great if uploaded to AUTonline; would be better if the lecturer's notes were uploaded for students access online; Lecturer can post it up later; I like this best because it allows the lecturer to record the lessons with ease;

The TPC_ON 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 records of the lecturer notes as a valuable feature where they have been made available. 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:

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;

There are a number of issues related to notetaking by students and note-record 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. Clearly the temporal nature of notes is changed, and no longer limited to what has not already been erased from a board. Although not continuously visible, previously written notes (even from earlier sessions) can be scrolled back into visibility at any time, and parts of interest can be zoomed in to allow inspection of detail. These issues are beyond what can be addressed within this paper and will be a matter for further research and reporting.

As with all handwritten modes, there remain issues related to the legibility of the lecturer's handwriting and expertise in using the technology:

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

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. Although common approaches are beginning to develop, definitive guidelines for good practice have not been promulgated. Despite being at an early stage of development, the study has shown that the penTPC OneNote mode to have the highest student rating, being judged significantly better than all other modes.

5 CONCLUSIONS

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

PowerPoint <

< Document Camera

<< Whiteboard

<<< Tablet PC with PPT and Annotations

<<<< Tablet PC and OneNote)

There were statistically significant differences in preferences, and meaningful effect sizes, between different modes.

Comments made by students suggest that preferences are based on valuing teaching technology modes that:

- display material in a format that is clearly visible throughout the class environment;
- support the display of live step by step development;
- support inclusion of other material, such as figures and tables
- can provide a record of notes that can be made available online

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 nature of *lecturer* responses to the use of Tablet PC technology will be reported in forthcoming research. The specific issues of student notetaking in class and lecturer provision of notes (both prior and post a session), and in the context of developments in software and pedagogical approaches, are also issues that will be examined.

This research has implications across a range of institutional roles and functions.

If use of pen-enabled Tablet PC technology is to become a teaching standard, managers will need to ensure all teaching staff engaged in these areas have access to such a device. In the study university, lecturers not currently using the technology have spoken of pressure from students for its adoption, but there are not yet consistent institutional policies and procedures to make such devices automatically available.

For those in charge of space management and development (estates planners), the requirements for the generic classroom may need to change if the Tablet PC is to become a standard for classroom delivery. The physical layout and height of lecterns and positioning of cables may need redesign to better support tablet writing. The specifications for suitable (high definition) data projectors and screens may need to be refined and implemented across all rooms. 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.

As stated at the outset, this study looked at delivery modes for mathematics-intensive 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. While it is apparent from this study that the penTPC provides an effective technology for maintenance of this approach, especially within larger classrooms, it is also apparent that the technology has capabilities that facilitate the development of different approaches.

PuenteDura (2010) described technology as having a potential to be used, in a progression, at a level of substitution, augmentation, modification or redefinition (abbreviated as SAMR). The penTPC can be more than just a substitute for, or a functional improvement over, the whiteboard. By providing support for delivering and recording handwriting in all forms of a digital environment, it has the potential to enable substantive modification and redefinition of learning and teaching approaches, and reconsideration of what is best done in class and what is best done outside of class. When students, and not just the lecturers, can be guaranteed to have access to these devices the scope for change is further enhanced.

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