Challenging assumptions about relationships between mathematics pedagogy and ICT integration: surveying teachers in English secondary schools

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This study investigates associations between mathematics pedagogy and teachers' integration of Information Communication Technologies (ICT). As an early adopter of presentation-oriented hardware and software in mathematics classrooms, England represents a critical case for investigating associations between mathematics pedagogy and teachers' integration of ICT into classroom practice. This paper reports the results of a survey of English secondary mathematics teachers' use of ICT (n=183). Using Rasch analysis to construct a measure of mathematics pedagogy, a consistent trend is found between frequent use of 'teacher-centred' software and a more 'student-centred' orientation. The analysis also suggests that some 'teacher-centred' practices involving ICT may instead be construed as 'dominant' practices. Taken together with case-study evidence of teachers' ICT integration from research on technology in education, these findings challenge assumptions about relationships between mathematics pedagogy and ICT integration prevalent in the mathematics education literature.

Keywords: digital technology, mathematics education, mathematics pedagogy, technology integration

Introduction

Digital technology is often claimed to have the potential to transform the teaching and learning of mathematics (e.g. Hoyles, 2018). Research in mathematics education has tended to focus on digital technologies such as spreadsheets, dynamic geometry and graphing software (e.g. Pierce & Stacey, 2010; Zbiek et al., 2007). Claims that such software may transform teaching and enhance learning tend to assume a learner-centred pedagogy (Kaput, 1992; Roschelle et al., 2010; Zbiek et al., 2007). However, mathematics teachers make little use of such software in general. The difficulties of integrating such digital technologies into mathematics classrooms are welldocumented (Clark-Wilson et al., 2014) and, even with sustained professional development, teachers find such software hard to use optimally (Clark-Wilson & Hoyles, 2017; Roschelle et al., 2010).

In contrast, mathematics teachers do make frequent use of presentation-oriented software such as PowerPoint and computer assisted instruction (CAI) software (Cheung & Slavin, 2013) such as the *MyMaths.co.uk* website, a subscription site offering teachers pre-planned lessons, on-line homework and many other resources (Bretscher, 2014). There is some evidence that these digital technologies facilitate whole-class instruction and may maintain or even encourage teacher-centred pedagogies (e.g. Zevenbergen & Lerman, 2008). A clear finding from mathematics education research is that a teachers' pedagogic orientation is a key factor in their integration of ICT (Stein et al., 2007). However, the relationship between mathematics pedagogy and teachers' use of ICT, i.e. *how* teachers' orientation to mathematics pedagogy affects their use of ICT, remains poorly understood. In part, this is due to the lack of research focus on the digital technologies that teachers actually *do* use. This paper contributes by challenging assumptions about relationships between mathematics pedagogy and ICT integration prevalent in the mathematics education literature.

Surveying mathematics teachers' use of technology

International surveys indicate low ICT integration in mathematics classrooms, though such indicators mask considerable variation between and within countries and provide little detail into how and why teachers use ICT. For example, in a survey of 42 countries (Organisation for Economic Cooperation and Development [OECD], 2015), on average 32% of students reported that they, or their classmates, performed at least one of a range of seven mathematical tasks on a computer in the last month. A further 14% reported that only teachers demonstrated the use of computers – consistent with a finding of infrequent computer use in mathematics instruction (OECD, 2015). The 2011 Trends in International Mathematics and Science Study (Mullis et al., 2012) found that only a quarter of students on average reported using computers at least monthly during mathematics lessons.

Hennessy and London (2013) chart the rise of interactive whiteboards (IWBs) worldwide, with the United Kingdom (UK) as the clear leader. The UK was an early adopter of IWBs into mathematics classrooms: Moss et al.'s (2007) survey on the introduction of IWBs in London schools found that 65% of mathematics teachers reported using IWBs in most or every lesson. Given its leading role in the integration of IWBs, England (and the UK more widely) represents a critical case for investigating associations between mathematics pedagogy and teachers' integration of ICT into classroom practice. Hence this paper investigates such associations through a survey English secondary mathematics teachers' use of ICT (n=183).

Understanding mathematics teachers' use of technology

This paper adopts a socio-cultural perspective towards understanding mathematics teachers' use of technology, acknowledging that a range of social factors influence mathematics teachers' use of ICT, such as cultural beliefs and the school and classroom context (Cuban, 2001). Stein et al. (2007) highlight *contextual features* at school level, such as time available for planning and instruction, school and departmental cultures, and teacher support through professional development, as factors that may influence mathematics teachers' use of ICT. Similarly, Ruthven (2009) describes *working environment*, that is, the physical location and layout of the classroom, as a structuring factor of teaching with technology, shaping routines for classroom organisation.

Critically, the perspective on technology use adopted in this paper views teachers as sense-makers (Spillane, 2006), actively interpreting hardware and software in a participatory relationship with technology (Remillard, 2005). In particular, this means that the design and nature of hardware or software is an ingredient in, but does not determine, the way individual teachers interpret and make use of particular technologies in their classroom practice. Similarly, teachers' pedagogic orientation is an important ingredient in their integration of ICT (Stein et al., 2007). Teaching experiences (involving ICT) may also influence teachers' pedagogic orientation (Clark-Wilson & Hoyles, 2017).

Modelling mathematics pedagogy

Drawing on Pampaka et al. (2012), I model mathematics pedagogy as a continuum between two 'opposites' conceptualised as a 'teacher-centred' versus a 'student-centred' orientation towards teaching mathematics. This model enables me to take advantage of Pampaka et al.'s (2012) qualitative and statistical validation of an interval measure of mathematics pedagogy. A teacher-centred orientation emphasises the importance of the teacher and instruction; conversely, a student-centred orientation places emphasis on students and their learning. Pampaka et al. (2012) identify teacher-centrism with a transmissionist approach and student-centrism with a connectionist or 'guided-discovery' approach, informed by Askew et al.'s (1997) three ideal-types of (transmissionist, discovery and connectionist) orientations to mathematics pedagogy.

From the outset, I acknowledge that modelling mathematics pedagogy in this way is a simplification and, in later sections, I re-visit the model to offer a critique. For example, Swan (2006) found that transmission-oriented teachers reported a greater frequency of teacher-centred practices, and that while discovery teachers reported a greater frequency of student-centred practices, connectionist teachers reported the most student-centred practices of all. This suggests that student-centrism in Pampaka et al. (2012) may represent an amalgam of both connectionist and discovery practices. Indeed, whilst their data showed an acceptable fit to the assumption of unidimensionality, implemented in Rasch analysis, they interpret some of their results as potential evidence of a second dimension of student-centred practice, concluding that the multidimensionality of the scale is worthy of further study. However, this multidimensionality has not been addressed in subsequent research using the scale (e.g. Pampaka & Williams, 2016).

Methodology

This study aims to take an initial step towards understanding how mathematics pedagogy and teachers' use of ICT are associated. A sufficiently large sample of cases was therefore required to allow for such an investigation. Pampaka et al.'s (2012) sample of 110 teacher-cases was sufficient to explore associations between mathematics pedagogy and learner dispositions. Directly observing teachers' ICT use and mathematics pedagogy was not practically possible for a sample of this size. Hence this study necessarily employed a survey methodology, using self-report items to collect data from a sample of 183 English secondary mathematics teachers on their use of ICT and their orientation towards mathematics pedagogy.

Survey instrument

The survey was designed to collect self-report data on mathematics teachers' use of ICT in line with the theoretical perspective previously outlined. Items on the frequency of mathematics teachers' use of hardware and software and their pedagogic practices involving ICT were included in Section B of the survey, entitled *ICT use in your own mathematics teaching*. These items were divided between using software in a whole-class context with an IWB and in a context where students have direct access to software, e.g. in a computer suite, to account for *contextual features* (Stein et al., 2007) and differences in the *working environment* (Ruthven, 2009) that might influence teachers' use of ICT. Another aspect of technology integration, the *centrality* of ICT to teachers' classroom routines (Anthony, 2011), was beyond the scope of this survey. This remains a limitation of the present study.

Dynamic geometry, spreadsheet and graphing software were included as stereotypically student-centred software in the sense that research on such software in mathematics education tends to assume a learner-centred pedagogy (Kaput, 1992; Roschelle et al., 2010; Zbiek et al., 2007). By contrast, IWB software, PowerPoint, *MyMaths* and 'Other websites' were included as stereotypically teacher-centred software in the sense that there is some evidence that these digital technologies facilitate whole-class instruction (e.g. Zevenbergen & Lerman, 2008). Other software, such as email and word-processing software, were included since they are available to teachers, but not identified as either stereotypically teacher- or student-centred.

The ICT pedagogic practices items were originally designed to be either teacher or student-centred. Some of these items were intended to be analogous to Pampaka et al.'s (2012) items, using a similar stem but presented in an ICT context e.g. in a whole-class context, '*Using ICT, I avoid students making mistakes by* *explaining things carefully first'* was a teacher-centred item and, in a context where students have direct access, '*I encourage students to work collaboratively'* was a student-centred item. Other items were informed by research on technology in mathematics education: exploring mathematical discrepancies (Guin & Trouche, 1999), 'de-bugging' and embracing 'hiccups' (Clark-Wilson & Hoyles, 2017) are important in using software effectively as part of a student-centred pedagogy. By contrast, preventing discrepancies or avoiding difficulties were designed to reflect teacher-centred practices involving ICT. Student-centred ICT pedagogic practice items are shown in italics in Tables 4 and 5. The complete item stems are available in Appendix A of the Supplemental Materials.

In addition, a measure of mathematics pedagogy was necessary. Pampaka et al.'s (2012) instrument was chosen for this purpose because, as noted in the preceding section, it enables construction of a previously-validated, interval measure of mathematics pedagogy. Moreover, the instrument was specifically designed to measure mathematics pedagogy in English classrooms, albeit in post-compulsory education. Pampaka et al.'s (2012) items comprised Section C of the survey instrument, entitled *Your own mathematics teaching in general,* relating to pedagogic practices in teaching mathematics in general i.e. not specific to ICT. The item-stems describe classroom activities associated with student-centred or teacher-centred practices. The full set of items is listed in Figure 1. Teachers were asked to indicate the frequency with which these activities occurred in their classroom practice on a five-point scale: almost never, occasionally, about half the time, most of the time, almost always. Although the items relate to teachers' classroom practices rather than the specific beliefs that underpin a teacher- or student-centred orientation per se, following Pampaka et al.'s (2012) argument, the teachers' responses to these items provide an indicator of their espoused theories (Argyris & Schon, 1974) of teaching practice. Hence they may be taken as an indirect indicator of teachers' teacher- or student-centred approach to mathematics pedagogy. A more detailed description of the full survey instrument, its development and the survey sample are presented in Bretscher (2014).

Survey sample

The aim of this exploratory study was to indicate where associations between mathematics pedagogy and ICT use might lie, rather than to provide conclusive results. Hence a purposive (rather than representative) sample was selected to provide a better chance of identifying associations between mathematics pedagogy and ICT use. Sample selection was directed towards critical cases of student- and teacher-centred orientation in relation to ICT use, specifically aiming for technology enthusiasts who would represent strongly teacher- or student-centred practice involving ICT if any association were present. Technology enthusiasts or teachers wishing to be seen as frequent users of ICT were assumed to be more likely to respond to a questionnaire about ICT use. This was borne out by the resulting sample (n=183) with only 9.0% of survey respondents stating they use ICT less or much less frequently whereas 33.5% report they use ICT more or much more frequently in comparison to their maths department colleagues (Bretscher, 2014). Whilst a teacher-centred orientation is likely to be common amongst secondary school teachers (Askew et al., 1997; Pampaka et al., 2012), student-centred teachers were expected to be relatively scarce. Sample design therefore aimed to ensure a sufficient number of student-centred teachers were included. I judged that schools linked with universities through initial teacher education programmes were more likely to foster teachers with student-centred orientations. Hence questionnaires were sent to teachers in mathematics departments in 87 secondary schools selected mainly through contacts with teacher educators in three English universities. Nine questionnaires were sent to each school and 50 schools agreed to take part. A total of 188 completed individual teacher questionnaires were returned, a median of 5 questionnaires per school. Of these, data from 183 teachers were entered for statistical analysis; 5 were removed due to missing data in Section C of the survey. Directing the questionnaire at school level meant that teacher-respondents were clustered in schools: twelve schools returned only one completed questionnaire, whilst one returned all nine. Assuming teachers in mathematics departments tend to develop a shared approach to mathematics pedagogy and ICT use, such clustering might support identifying technology enthusiasts who would represent strongly teacher- or student-centred practice involving ICT, increasing the chance of identifying associations between mathematics pedagogy and ICT use.

Measure construction and statistical analysis

The purpose of data analysis was to explore associations between mathematics pedagogy and teachers' ICT use, in terms of their frequency of ICT use and their pedagogic practices involving ICT. An interval-level scale of mathematics pedagogy was required so that parametric tests, specifically t-tests, could be conducted between groups of frequent and occasional ICT users to identify whether such associations exist. Following Pampaka et al. (2012), the Rasch rating scale model (Andrich, 1999) was selected because it provides a method of constructing an interval measure of mathematics pedagogy from the survey data.

Teachers with a more teacher-centred orientation were expected to be more likely to endorse items describing teacher-centred practices and less likely to endorse student-centred items. Rasch modelling assumes the tendency of individual teachers to endorse items and the tendency for a particular item to be endorsed can be measured on the same scale. Broadly, the probability of a teacher endorsing a particular item is modelled as being dependent on the difference between the teacher's tendency to endorse items and the item's tendency to be endorsed. The Rasch rating scale model equation is provided in Appendix B in the Supplemental Materials.

Teacher-centred items were coded '1' = 'almost never' and '5' = 'almost always'; whereas student-centred items were reverse-coded '5' = 'almost never' and '1' = 'almost always'. In general then, a teacher with a teacher-centred orientation would be expected to record higher raw scores for both types of item than a teacher with a relatively student-centred orientation. Similarly, for teachers, a higher numerical score on the Rasch scale of mathematics pedagogy would be interpreted as indicating a more teacher-centred orientation, whilst a lower score indicates a more student-centred orientation. Note that, though teachers with a teacher-centred orientation would score numerically higher on the Rasch scale of mathematics pedagogy, in no way should this be taken to mean that teacher-centred pedagogy is 'better' than student-centred pedagogy.

The scale of mathematics pedagogy resulting from Rasch analysis should be interpreted with caution due to the potential for multidimensionality, noted earlier in the section on 'Modelling mathematics pedagogy'. Reverse-coding of student-centred items also makes interpreting teacher and item scores problematic. However, a major strength of Rasch analysis is that, because the model is based on three key assumptions of unidimensionality, invariance and local independence, the extent to which these assumptions hold true may be tested empirically (Panayides, Robinson, &

Tymms, 2010). Fit statistics provide diagnostic tools for judging how well the data comply with the assumptions underlying the Rasch model. Following Pampaka et al. (2012), in this study, values of infit and outfit above 1.3 provide an indicator of misfit.

Data that could be analysed statistically were manually entered into *PASW Statistics 18.0* initially. This package was used to generate descriptive statistics (i.e. frequency distributions and means) and calculate inferential statistics (t-tests) where appropriate. Descriptive statistics, relating to teachers' ICT use, are reported in Bretscher (2014). An independent data coding check, based on a 10% sample of questionnaires, gave a coding reliability of greater than 99.9%.

Rasch analysis was carried out using the *Winsteps* (2011) software. Once the measure of mathematics pedagogy was constructed, teachers' measures were imported back into the *PASW Statistics 18.0* software. For items on frequency of software use and ICT pedagogic purposes, categories were collapsed to frequent and occasional users to provide a relative rather than absolute indication of ICT use, representing a meaningful distinction in practical terms (de Vaus, 2014). For software used in a whole-class context, frequent use corresponds to the concatenation of categories 'once per week' and 'almost every lesson', with occasional use corresponding to categories 'never', 'annually' and 'once or twice per term'. Where students have direct access to software, due to levels of use being lower overall, frequent use was considered to include 'once or twice per term'. For ICT pedagogic practices, frequent occurrence corresponds to categories 'almost always' and 'most of the time'; whilst occasional occurrence corresponds to categories 'almost never', 'occasionally' and 'half the time'. Independent samples t-tests were carried out comparing the mean measure of mathematics pedagogy for frequent and occasional users of ICT and of teachers reporting frequent and occasional occurrence of pedagogic practices using ICT. Levene's test for equality of variances was checked. On the occasions where equality of variances could not be assumed the appropriate degrees of freedom and adjusted t-statistics were reported.

Results of measure construction: a scale of mathematics pedagogy

Taken together, the results from the Rasch analysis reported in this section suggest that Pampaka et al.'s (2012) items constitute a reasonable scale for measuring mathematics pedagogy. The Rasch analysis of data from Pampaka et al.'s (2012) items achieved a person reliability score of 0.83 suggesting an acceptable overall level of consistency and reliability. Table 1 shows the item measures, fit statistics and point-measure correlation resulting from the Rasch analysis of the data. The item stems are shown in Figure 1. The fit statistics for all except six items, shown in bold in Table 1 (C6, C10, C22, C23, C24, C26), were below the 1.3 threshold of concern. Removing these items only increased person reliability score to 0.86. Items C6, C22, C24 and C26 were also mis-fitting in Pampaka et al.'s (2012) data. They argued on theoretical and methodological grounds that these items should not be excluded, since they may belong to a secondary dimension of student-centred teaching, and so may be interpreted differently by some student- or even teacher-centred teachers (Pampaka et al., 2012). These arguments are indicative of the potential multidimensionality of the scale, noted earlier in the section on 'Modelling mathematics pedagogy'. For example, Pampaka et al. (2012) suggest that C6 'working more slowly' may be seen as part of a laissez-faire student-centred or discovery approach as well as encouraging more thoughtful work through a connectionist or guided-discovery approach.

[Table 1]

[Figure 1]

In addition, item C26 ('knowing exactly what maths the lesson will contain') is intended as a teacher-centred item, suggesting the lesson is controlled to exclude non-standard mathematics. However, Pampaka et al. (2012) suggest some student-centred teachers may instead interpret this item as regarding subject matter knowledge, i.e., that they should have knowledge of all the mathematics that 'might' arise in the lesson. Similar arguments can be made for the other mis-fitting items.

In conclusion, a decision was made to retain the six mis-fitting items in the model since this is advantageous in maintaining the possibility of comparison across data sets for the purposes of future research. Although there is some statistical evidence to suggest their exclusion, following Pampaka et al.'s (2012) arguments, this was outweighed on the grounds of theoretical and methodological considerations. In particular, the six items may still contribute to aspects of mathematics pedagogy, thus they are retained for the purpose of maintaining content validity (Bohlig et al., 1998). A principal components analysis of Rasch residuals suggests a second dimension in the data may exist, however the evidence remains inconclusive and still requires further research (see Appendix C, Supplemental Materials).

Figure 1 shows the distribution of both items and survey respondents on the resulting scale of mathematics pedagogy, in a diagram adapted from the item-person map provided by the *Winsteps* software. On the right-hand side, the distribution of teachers is displayed as a histogram, with a higher score interpreted as indicating a more teacher-centred orientation. Conversely, a lower score is indicative of a more student-centred orientation. On the left-hand side, the approximate position of items on the scale is shown, indicating the tendency of an item to be endorsed by teachers.

In other words, normal-coded, teacher-centred items placed low on the scale were more likely to be endorsed, whilst those placed high on the scale were less likely to be endorsed by teachers. For reverse-coded items, intended to describe student-centred practices, the opposite holds e.g. C15. The positive mean person measure (0.17), displayed on the histogram, indicates that the set of test-items was slightly too 'easy' for the target sample. That is, there are too few items that the most teacher-centred teachers find 'difficult' to endorse to differentiate them; whilst there are too few sufficiently student-centred teachers to provide good information about the items teachers find 'easiest' to endorse. Another interpretation of the mean person measure is that the population of teachers is somewhat skewed towards a teacher-centred orientation. Note that item C27 was not included in this study because Pampaka et al. (2012) discarded it from their analysis. In retrospect, it should have been included.

Results

I report findings regarding associations between the frequency of teachers' use of particular types of ICT and the measure of mathematics pedagogy, before going on to explore associations between this measure and teachers' self-reported pedagogic practices involving ICT.

A consistent trend between frequent use of teacher- (as well as student-) centred software and a more student-centred orientation

Tables 2 and 3 show the number of teachers reporting frequent and occasional use of software in a whole-class context with an IWB and in a context where students have direct access to software, e.g. in a computer suite, respectively. Also reported in Tables 2 and 3 are the results of t-tests comparing the difference in mean measure of mathematics pedagogy for frequent and occasional users of software in a whole-class context and where students have direct access to technology respectively. A positive difference indicates that frequent users have a higher mean measure of mathematics pedagogy and thus a more teacher-centred orientation than occasional users. A negative difference in mean measure of mathematics pedagogy means that frequent users of ICT have a lower mean measure and hence a more student-centred orientation than occasional users.

[Table 2]

Overall there is a consistent trend for teachers who make frequent use of ICT to identify themselves as more student-centred than occasional users. For those resources viewed as teacher-centred, this trend is statistically significant for each of IWB software, PowerPoint, the *MyMaths* website and Other websites in a whole-class context with an IWB – see Table 2. For software identified with student-centred pedagogy, regarding use in a whole-class context, this trend is statistically significant only for dynamic geometry software, though use of spreadsheets approached the 5% significance level. In addition, in a whole-class context, 55-80% of teachers reported frequent use of teacher-centred software (IWB software, PowerPoint, the *MyMaths* website and Other websites). In contrast, 15-30% of teachers reported frequent use of software identified with student-centred pedagogy (spreadsheet, dynamic geometry and graphing software).

[Table 3]

Where students have direct access to technology, for teacher-centred software, the trend for frequent users to identify as student-centred is significant for the *MyMaths* website and Other websites – see Table 3 – with IWB software and PowerPoint approaching the 5% and 10% significance levels respectively. For software identified with student-centred pedagogy, where students have direct access, this trend is significant for each of graphing, spreadsheet and dynamic geometry software. In addition, in this context, roughly 70% of teachers reported frequent use of the *MyMaths* website and Other websites. A small majority of teachers reported frequent use of spreadsheet (56%), with graphing software and dynamic geometry slightly lower at 48% and 45% respectively.

Dominant as opposed to teacher-centred practices: associations between ICT pedagogic practices and mathematics pedagogy

Tables 4 and 5 display the results of t-tests comparing the difference in mean measure of mathematics pedagogy between teachers reporting frequent occurrence of ICT pedagogic practices and those reporting occasional occurrence in their ICT lessons in a whole-class context and in a context where students have direct access to software respectively.

[Table 4]

[Table 5]

Four practices, designed as teacher-centred items, appear instead to be dominant or prevailing practices in the sense that they had the highest proportions of teachers reporting frequent occurrence (for the lesson-context) and were not associated with pedagogic orientation. For lessons in a whole-class context, two items designed to be teacher-centred had the highest proportions of teachers reporting frequent occurrence: *I use ICT for presentation purposes* (75%) and *I control the software on the IWB* (80%), see Table 4. For lessons where students have direct access to technology, two items designed to be teacher-centred had the highest proportions of teachers reporting frequent occurrence: *Students' use ICT to practise skills* (50%) and *I provide precise instructions for software use* (49%), see Table 5. None of these four items showed a statistically significant association with the measure of mathematics pedagogy. Indeed, none of the ICT pedagogic practice items, in particular not one of the items intended to be teacher-centred, showed a statistically significant association between frequent occurrence and identifying as more teacher-centred. Of those items that showed a statistically significant association with the measure of mathematics pedagogy, all were designed as student-centred items. For these items, reporting frequent occurrence of the student-centred ICT pedagogic practices was associated with identifying as more student-centred towards mathematics pedagogy in general.

Discussion

This paper presents two sets of findings that add to our understanding of how mathematics pedagogy and teachers' use of ICT are associated, in the context of English secondary schools.

Firstly, a consistent trend for frequent users of teacher- (as well as student-) centred software to identify themselves as having a more student-centred orientation was found. This trend reached statistical significance for all four types of stereotypically teacher-centred software (IWB software, PowerPoint, *MyMaths* and Other websites) used in a whole-class context with an IWB and for *MyMaths* and Other websites in a context where students have direct access to technology. In addition, for each of the teacher-centred resources, a majority of teachers reported frequent use in both contexts (except for IWB software in a context where students have direct access to technology). In contrast, where students have direct access to technology, the trend reached significance for all three types of software identified with student-centred pedagogy where frequent users were in a near or small majority. For stereotypically student-centred software use in a whole-class context, frequent use of such software was in the minority and for only dynamic geometry software did the trend reach significance. The purposive survey sample, directed towards selecting technology enthusiasts who would represent critical cases of student- and teacher-centred ICT use, serves to underline these findings.

There are many potential explanations for this first set of findings: perhaps teachers identifying as more student-centred also tend to be more generally innovative. The findings from this study also provide evidence of a trend relating to working environment, where ICT use in a whole-class context is more strongly associated with teacher-centred resources than contexts where students are given direct access to technology and the reverse for student-centred software. On their own, these findings do not constitute direct evidence that teacher-centred software is being used in more student-centred ways by teachers who identify as having a more student-centred orientation. However, evidence does exist from research on technology in education that mathematics teachers can use teacher-centred software in a whole-class context with an IWB, at least, in more student-centred ways. For example, Moss et al. (2007) detail a lesson on factorisation in algebra where a teacher coordinated whole-class discussion around a slide designed with IWB software to co-construct knowledge with pupils. The slide embedded drag-able, coloured rectangles, using an area representation of multiplication to connect factorisation with pupils' prior knowledge and colour to highlight mathematical patterns. Glover et al.'s (2007) observational study, where 12 of 34 mathematics lessons observed using IWBs showed the highest level of interactivity with the teacher orchestrating "full dialogue with and between pupils", suggests that Moss et al.'s (2007) case study may not be unique.

Taken together with such evidence, the first set of findings from this study challenges assumptions in the mathematics education literature that presentation-oriented software, such as PowerPoint, and CAI, such as *MyMaths*, *HegartyMaths* or *Khan Academy* websites, maintain or even encourage teacher-centred pedagogies because they appear to facilitate whole-class instruction (e.g. Zevenbergen & Lerman, 2008). In contrast, results showing associations between frequent use of dynamic geometry software, spreadsheets and graphing software and a more student-centred orientation are not challenging in the same way since mathematics education research suggests that such software is compatible with more student-centred practices. Whilst mathematical software of this type is assumed to support teachers and pupils in making connections, for example between multiple representations (Kaput, 1992), the first set of findings, taken together with evidence from research on technology in education, suggests that 'teacher-centred' software could *also* be important in supporting student-centred practices.

Secondly, four practices, designed as teacher-centred items, appear instead to be dominant or prevalent practices since they had the highest proportions of teachers reporting frequent occurrence (for the lesson-context) and were not associated with pedagogic orientation. This second set of findings supports Cuban's (2001) conclusion that school structures make classrooms highly resistant to technological innovation, meaning the up-take of technology, such as giving students access to computers, remains relatively marginal in classroom practice. On the other hand, where the use of a new technology does become widespread, it is because this technology supports existing, established practices e.g. teacher-centred instruction (Cuban, 2001).

The finding of dominant practices involving ICT indicates potential difficulties in modelling mathematics pedagogy as a teacher-centred versus student-centred continuum based on self-reported practices. If mainstream practices appear (superficially) the same, irrespective of teachers' pedagogic orientation, then both teachers with teacher- and student-centred orientations may endorse such practices whilst potentially interpreting them in subtly different ways. The findings from this paper, taken together with research from technology in education, suggest that this may be the case for dominant practices involving ICT. Such difficulties are also apparent in the results of constructing the measure of general mathematics pedagogy: two of the most highly endorsed items (C6, C26) showed misfit in both the present and the original study (Pampaka et al., 2012). As a result, modelling mathematics pedagogy as a teacher- versus student-centred continuum may risk characterising teachers' pedagogic orientations based on conspicuously different but relatively marginal practices, such as the use of 'student-centred' software, whilst eliding subtle but important differences in dominant practices.

The geographical limitations of the sample mean that the findings may not generalise within England. The mean measure of mathematics pedagogy indicated this sample of English secondary mathematics teachers were relatively teacher-centred. This suggests the measure of mathematics pedagogy and findings reported above need further testing both in England and in countries with different pedagogic profiles and patterns of ICT use.

Conclusion

This paper makes a contribution by challenging (implicit) assumptions about relationships between mathematics pedagogy and ICT integration prevalent in the literature. Research in mathematics education has found that a teachers' pedagogic orientation is a key factor in their integration of ICT (Stein et al., 2007). However, the relationship between mathematics pedagogy and teachers' use of ICT, i.e. how teachers' orientation to mathematics pedagogy affects their use of ICT, remains poorly understood. Perhaps as a result, use of digital technologies valued by research on mathematics education for their transformative potential, such as spreadsheets, dynamic geometry and graphing software (e.g. Pierce & Stacey, 2010; Zbiek et al., 2007), tends to assume a learner-centred pedagogy. Similarly, presentation-oriented software, such as PowerPoint, and CAI (Cheung & Slavin, 2013), such as the *MyMaths* website or similar sites such as *HegartyMaths* or *Khan Academy*, are often assumed by academics and mathematics educators alike to maintain or even encourage teacher-centred pedagogies because they appear to facilitate whole-class instruction (e.g. Zevenbergen & Lerman, 2008). Taken together with evidence from case studies in research on technology in education, the finding of a consistent trend between frequent use of teacher-centred software and a more student-centred orientation towards mathematics pedagogy challenges such assumptions.

This paper also contributes towards understanding the relationship between pedagogic orientations and teachers' self-reported practices. Specifically, modelling mathematics pedagogy solely as a teacher- versus student-centred continuum risks characterising teachers' pedagogic orientations based on conspicuously different but relatively marginal practices, whilst eliding subtle but important differences in dominant practices. For example, in describing their idealised connectionist, transmission and discovery orientations to mathematics pedagogy, Askew et al. (1997, p.50) emphasise: "The importance of these orientations lies in how practices, while appearing similar may have different purposes and outcomes depending upon differences in intentions behind these practices." The findings from this study, taken together with research on technology in education, suggest that teachers with teacher- and student-centred orientations may both endorse dominant practices involving ICT whilst potentially interpreting them in different ways. Thus key questions for future research on digital technology in mathematics education is to what extent do mainstream practices, e.g. using presentation and CAI-type software, differ subtly depending on teachers' orientation to mathematics pedagogy and how are these differences realised? Similarly, for Pampaka et al.'s (2012) instrument, two of the most highly endorsed items show misfit, suggesting that both teacher- and student-centred oriented teachers may endorse these practices whilst interpreting them differently. As such, there is a need for both qualitative and quantitative research based on a multi-dimensional model of mathematics pedagogy.

An implication of this study is that research is needed on the digital technologies that teachers actually do use in order to understand how mathematics pedagogy and teachers' use of ICT are related. Research in mathematics education has tended to focus on digital technologies such as spreadsheets, dynamic geometry and graphing software (e.g. Pierce & Stacey, 2010; Zbiek et al., 2007). However, use of these digital technologies is a marginal practice. Instead, the focus of research on digital technologies in mathematics education should shift towards investigating mainstream practice to understand how and why teachers use presentation-oriented and CAI-type software. Qualitative studies of classroom practice (e.g. Bozkurt & Ruthven, 2018) could shed light on how teachers use presentation-oriented software to support more student-centred practices. If such studies could identify ways to change mainstream use of ICT (even incrementally) then this might be more radical than a transformative change in marginal practice.

This study also has implications for practice in teaching and teacher education. Teachers might reflect upon what constitutes mathematically-principled use of presentation and CAI-type software. Similarly, teacher educators should include such technologies as part of the curriculum for initial teacher education and on-going professional development to support teachers in using such software in informed ways and to critically reflect upon what appears to be mainstream practice in their schools.

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Table 1. Item measures, fit statistics and point-measure correlation

Item	Raw score	Count	Measure	Model S.E.	Infit MNSQ	Outfit MNSQ	Pt-Measure Correlation
C1	647	180	-.43	.09	.97	.98	.54
C2	616	181	-.20	.08	.87	.86	.41
C3	552	181	.23	.08	.77	.77	.53
C4	719	183	-.92	.09	.93	.90	.40
C5	656	183	-.42	.08	.94	.96	.55
C6	738	183	-1.09	.10	1.39	1.42	.06
C7	567	183	.16	.08	.68	.70	.55
C8	401	182	1.17	.08	1.14	1.10	.44
C9	720	183	-.93	.09	.74	.74	.43
C10	624	182	-.22	.08	1.31	1.37	.29
C11	403	181	1.13	.08	.99	.96	.38
C12	621	183	-.18	.08	.75	.72	.51
C13	627	183	-.22	.08	1.02	1.02	.49
C14	442	183	.92	.08	.94	.93	.67
C15	448	183	.88	.08	.70	.69	.56
C16	520	183	.45	.08	.73	.74	.50
C17	696	182	-.76	.09	.83	.82	.53
C18	632	181	-.31	.08	.78	.81	.49
C19	647	183	-.36	.08	.85	.87	.66
C20	546	183	.29	.08	1.00	1.03	.30
C21	447	181	.85	.08	.90	.90	.50
C22	545	182	.28	.08	1.39	1.40	.29
C23	560	181	.16	.08	1.47	1.49	.24
C24	683	180	-.72	.09	1.44	1.49	.02
C25	483	180	.62	.08	.93	.92	.56
C26	700	182	-.79	.09	1.52	1.50	.34
C28	526	183	.41	.08	1.11	1.12	.32
Mean			.00	.08	1.00	1.01	
S.D.			.65	.01	.25	.26	

Table 2. Mean difference in measure of mathematics pedagogy for frequent and occasional users of software when used in a whole-class context e.g. with an IWB

Whole-class context: frequency of software use	n freq, occ	Mean difference freq - occ	t-stat	df	p-value
CD-Roms	36; 139	-.100	-1.01	173	.313
Database	23; 151	-.088	-.738	172	.462
Email	53; 119	-.086	-.991	170	.383
Graphing software	49; 122	-.017	-.185	169	.853
Dynamic geometry	30; 145	-.324	-3.13	173	.002*
IWB software	146; 33	-.285	-2.86	177	.005*
MyMaths	116; 64	-.284	-3.58	178	p<.001*
Other websites	112; 61	-.315	-3.92	171	p<.001*
PowerPoint	107; 72	-.251	-3.21	177	.002*
Spreadsheet	45; 134	-.174	-1.92	177	.056
Word	74; 105	-.119	-1.50	177	.137

* indicates statistical significance at the 5% level. Occasional user = (never, annually, once or twice per term); Frequent user = (once per week, almost every lesson).

Table 3. Mean difference in measure of mathematics pedagogy for frequent and occasional users of software in a context where students have direct access to the software e.g. in a computer suite

Direct student access: frequency of software use	n freq, occ	Mean difference freq - occ	t-stat	df	p-value
CD-Roms	33; 136	-.129	-1.26	167	.208
Database	29; 143	-.013	-.124	170	.902
Email	45; 123	-.231	-2.54	166	.012*
Graphing software	88; 85	-.240	-3.02	171	.003*
Dynamic geometry	83; 90	-.323	-4.20	171	p<.001*
IWB software	69; 102	-.158	-1.94	169	.054
MyMaths	129; 44	-.233	-2.54	171	.012*
Other websites	126; 48	-.328	-3.78	172	p<.001*
PowerPoint	90; 82	-.123	-1.51	155.5	.133
Spreadsheet	103; 72	-.227	-2.83	173	.005*
Word	89; 84	-.216	-2.72	171	.007*

* indicates statistical significance at the 5% level. Occasional user = (never, annually); Frequent user = (once or twice per term, once per week, almost every lesson)

Table 4. Mean difference in measure of mathematics pedagogy for teachers reporting frequent and occasional occurrence of pedagogic practices using ICT in a whole-class context e.g. with an IWB

Whole-class context: frequency of practices	n freq, occ	Mean difference freq - occ	t-stat	df	p-value
teacher presentation	138; 40	.038	.406	176	.685
student discussion	78; 102	-.312	-4.15	178	p<.001*
teacher control	146; 33	.060	.491	40.3	.626
explore students' ideas	50; 130	-.250	-2.94	178	.004*
prevent discrepancies	74; 96	-.013	-.166	168	.868
students control	39; 141	-.338	-3.71	178	p<.001*
highlight discrepancies	55; 118	-.152	-1.79	171	.075
avoid mistakes	77; 99	.135	1.70	174	.090

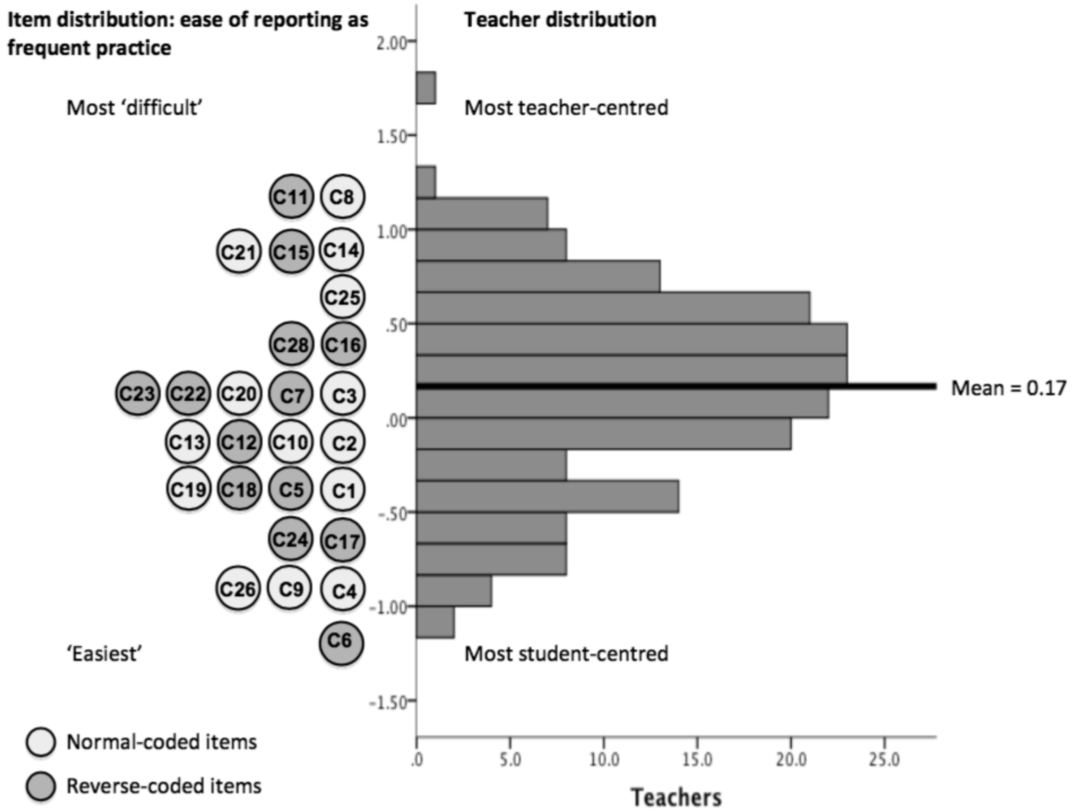
* indicates statistical significance at the 5% level. Student-centred items in *italics*. Occasional = (almost never, occasionally, half the time); Frequent = (most of the time, almost always)

Table 5. Mean difference in measure of mathematics pedagogy for teachers reporting frequent and occasional occurrence of pedagogic practices using ICT in a context where students have direct access to the software e.g. in a computer suite

Direct student access: frequency of practices	n freq, occ	Mean difference freq - occ	t-stat	df	p-value
practise skills	92; 75	-.028	-.337	165	.737
work collaboratively	90; 82	-.236	-3.04	170	.003*
'get a feel' for the software	80; 92	-.258	-3.34	170	.001*
explore discrepancies	22; 143	-.271	-2.31	163	.022*
individual work	70; 100	-.063	-.782	168	.436
investigate problems	61; 111	-.212	-2.60	170	.010*
provide precise instructions	90; 77	.093	1.15	165	.252
avoid technical difficulties	51; 118	-.014	-.164	167	.870

* indicates statistical significance at the 5% level. Student-centred items in *italics*. Occasional = (almost never, occasionally, half the time); Frequent = (most of the time, almost always)

Figure 1. Scale of mathematics pedagogy for secondary mathematics teachers



C1	Students work through exercises.		C15	Students discuss their ideas.
C2	Students work on their own, consulting a neighbour from time to time.		C16	Students work collaboratively in pairs.
C3	Students use only the methods I teach them.		C17	Students invent their own methods.
C4	Students start with easy items and work up to harder questions.		C18	Students work on substantial tasks that can be worked on at different levels.
C5	Students choose which questions they tackle.		C19	I tell students which questions to tackle.
C6	I encourage students to work more slowly.		C20	I encourage students to work more quickly.
C7	Students compare different methods for doing questions.		C21	I go through only one method for doing each question.
C8	I teach each topic from the beginning, assuming they know nothing.		C22	I find out which parts students already understand and don't teach those parts.
C9	I teach the whole class at once.		C23	I teach each student differently according to individual needs.
C10	I try to cover everything in a topic.		C24	I cover only the important ideas in a topic.
C11	I draw links between topics and move back and forth between topics.		C25	I teach each topic separately.
C12	Students work collaboratively in small groups.		C26	I know exactly what maths the lesson will contain.
C13	I avoid students making mistakes by explaining things carefully first.		C28	I jump between topics as the need arises.
C14	I tend to follow the textbook closely.			

Note: C27 was not included in this study

Figure captions

Figure 1. Scale of mathematics pedagogy for secondary mathematics teachers