Journal of Humanistic Mathematics

Volume 3 | Issue 1 January 2013

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Recommended Citation

Rowlett, P. J. "Developing a Healthy Scepticism About Technology in Mathematics Teaching," *Journal of Humanistic Mathematics*, Volume 3 Issue 1 (January 2013), pages 136-149. DOI: 10.5642/jhummath.201301.11 . Available at: http://scholarship.claremont.edu/jhm/vol3/iss1/11

JHM is an open access bi-annual journal sponsored by the Claremont Center for the Mathematical Sciences and published by the Claremont Colleges Library | ISSN 2159-8118 | http://scholarship.claremont.edu/jhm/

Developing a Healthy Scepticism About Technology in Mathematics Teaching

Cover Page Footnote

I am registered for my PhD at Nottingham Trent University with Dr. G. Tranfield, Prof. A. Sackfield and Prof. W. Cranton.

Developing a Healthy Scepticism About Technology in Mathematics Teaching

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Synopsis

A reflective account is presented of experiences which took place alongside a research project and caused a change in approach to be more sceptical about implementation of learning technology. A critical evaluation is given of a previous e-assessment research project, undertaken from a position of naive enthusiasm for learning technology. Experiences of teaching classes and designing assessment tasks lead to doubts regarding the extent to which the previous project encouraged deep learning and contributed to graduate skills development. Investigations of the benefits of another technology—in-class response systems—lead to revelations about learning technology: its enthusiastic introduction in isolation cannot be expected to produce educational benefit; instead it must address some pedagogic need and should be evaluated against this. Overall, these experiences contribute to a shift away from a naive enthusiasm to an approach based on careful consideration of educational need before technology implementation.

I am currently engaged in study for a PhD in e-assessment in mathematics. By *e-assessment*, or sometimes and equivalently *computer-aided assessment* (CAA), I mean to refer to tests administered to students via computer. The student is presented with questions on screen and inputs an answer which is marked by the computer, providing instant feedback. In short, I am interested in the use of computers to enhance the assessment process.

My current research project arose initially from work completed for my Masters dissertation. A change in emphasis and approach has taken place during this project, from naive enthusiasm for learning technology to a healthy scepticism and more considered approach directed to clear educational need. I don't remember a Damascene moment in relation to this change but a gradual shift based on my activities outside this project.

Moore [16, page 14] recommends drawing on a body of knowledge and experience ("theory"), through different contexts, to inform teaching practice. This theory is based on scholarship and also is informed by reflective evaluation of previous experience. It seems appropriate, using this model, to offer a reflection on the change in approach that has taken place during this project.

I began this project in part-time mode in 2004 and alongside this I have had a series of part-time jobs. I started as a computer technician, running websites and databases for statisticians (2004-7). Later I worked for a mathematics professional body, talking to undergraduate mathematics students around the U.K. about career options and what they might do after graduation (2008-10). I worked as a mathematics lecturer in a U.K. university (2008-9), giving mathematics content for science and business students and computational methods and graduate skills development for mathematicians. I worked to support learning and teaching through technology in a U.K. university mathematics department (2009-10) and I worked on a national project to support curriculum development projects and offer teaching and learning staff development in higher education mathematics (2010-12). Naturally, these experiences have shaped my outlook on pedagogy, and this in turn has influenced my PhD research.

In this essay, then, I do not seek to address my e-assessment project directly. Rather, I describe some of the other experiences I have had of teaching and of implementing learning technology, and how these have influenced my approach to my PhD work on e-assessment. This essay begins with a critical examination of my Masters dissertation and initial plans for my PhD research. It then goes on to describe my experiences of lecturing. I focus in particular on how these experiences informed my thinking about the need for deep learning and helped me develop an appreciation of the role assessment can play in the development of graduate skills, leading me toward an understanding of the process of deriving benefit from the implementation of technology. I do not attempt to detail all my previous experience, but to reflect on that which is relevant to a change of approach that has taken place during my research project.

1. A solution looking for a problem

My PhD research arose as a continuation of a previous project, my Masters dissertation ([19], summarised in [20]). I completed this dissertation as part of a computing Masters degree following a realisation in 2003 that the technologies used to dynamically generate HTML webpages could dynamically generate MathML code to present mathematics on the web. HTML is the language used to encode content on web pages and uses tags to indicate which parts of a document are headings, paragraphs, links, etc. In a similar way, MathML uses tags to encode mathematical structures. Many HTML webpages are actually output from a script which has drawn together particular page elements (items in your shopping cart, for example) into a unique page for you. Applying this approach to MathML, mathematics can be written which includes dynamically generated elements; in this case to produce questions for an e-assessment system which differ for each user.

I was aware, perhaps from my experience during my undergraduate mathematics degree, that practice is important in learning mathematics. I designed a system to make available to students self-test material on differentiation which would be marked by computer. Using pseudo-randomised constants in the functions to be differentiated, the system was capable of generating something in the region of nine million distinct questions from a dozen or so basic question types. A student using this system could reasonably expect to be able to practice for as long as they liked without running out of new questions to attempt.

The dissertation itself [19] has a strong focus on technology, with chapters explaining MathML and dynamic webpage technologies, and the main focus of the work is on applying the latter to the former to produce a computer-aided assessment system. A chapter on 'Mathematics and CAA' (pages 22–25) does mention some aspects of how people learn, but it has as its main focus issues arising from using technology to present mathematics assessments, including problems inputting mathematical notation and limitations of automated marking.

A user evaluation questionnaire was attempted but this gathered few responses. The evaluation chapter (pages 45–49) focuses instead on whether the system was generating sensible mathematics without error, based on limited use by students. Although users were considered in the concluding chapter (where, for instance, there is some concern expressed about "the small scope of the student usage evaluation"), the main conclusion is that "utilising the power of MathML through its dynamic manipulation has some merit when applied to the production of pseudo-randomised mathematics questions". This seems to mean only that it is indeed possible to use an e-assessment system to set valid questions using MathML and correctly mark them.

Exhibited in this work is clear pride in the efficiency of the approach (for the assessor); the system was capable of generating a relatively large quantity of 'output' for the amount of 'input' required. The starting point of this research was noticing what could be done with the technology and implementing this, simply because it was possible, without reference to wider pedagogic theory. In a way this was quite reasonable; I was applying what I had learned during my computing degree to the interesting area of computer-aided assessment. In that sense I remain proud of the work, but at the same time, the work now seems hopelessly naive, lacking any in-depth focus on educational aspects of what was being attempted.

I began my PhD with a similar approach. I was encouraged early on in this enterprise (2004/5) to write an account of my plans [21], and in this I describe my research as continuing the work started during my Masters dissertation and "investigat[ing] the application of other [similar] technologies to mathematics teaching and learning" (page 35). Again, the focus seems to be on what can be done with technology first and what might be needed second.

2. Deep learning of mathematical concepts

In 2008 I began lecturing a basic course in mathematics for business and science students who did not hold a recent qualification including mathematical topics relevant to their degree. Instinctively, I wanted to encourage the students into some understanding of the concepts behind the mathematical syllabus, rather than just treating mathematics as a set of techniques to be memorised. As a mathematician, I have a poor appreciation of how one might learn (certainly, remember) a technique without first understanding it. However, the students I was teaching were to use mathematics as a tool, a means to an end. In their home disciplines they would have problems which need to be solved using mathematics, and they were looking to me to teach them how to apply relevant techniques. In circumstances such as these, I wondered, is teaching the procedure of applying the technique sufficient?

In the context of my e-assessment project, a system which can generate millions of instances of a limited range of questions might be seen as supporting the latter type of learning. It helps students to memorise and practice the technique without necessarily supporting their understanding. But is that a problem?

Entwistle and Ramsden [7] contrast two main types of learning: "deep" (or "meaning") and "surface" (or "reproducing") (page 193). The deep approach is "internal", focused on the content of the article or problem and the knowledge, experience, and interests of the learner. The surface approach is "external", focused on the task and its requirements, with material "impressed on the memory for a limited period" and "no expectation that the content will become a continuing part of the learner's cognitive structure" (page 195).

Raine [18] regards the way mathematics has been taught to science students as procedural, "by constant repetition and coverage of all possible variants of a given problem, eventually to the extent that mathematics becomes indistinguishable from pattern matching" (page 14). Fuson *et al.* [8] suggest this procedural way of teaching mathematics "often overrides students' reasoning processes, replacing them with a set of rules and procedures" (pages 217–218). These descriptions certainly sound like they would fit a massively randomised e-assessment system. Since the computer is applying a set of rules and procedures for pattern matching, we can hardly expect that repeated use of the system would encourage anything deeper from students. So does this sort of learning suit the requirements some students have to just learn to apply mathematical techniques?

Fuson *et al.* [8] argue that focusing the instruction on procedural knowledge is ineffective and causes a disconnect from the meaning behind the mathematics, evidenced by students failing to correct erroneous answers which are clearly unrealistic. Raine remarks that the surface approach works "until you change the context and start asking for applications of the techniques in unfamiliar surroundings" [18, page 14]. A study in which students could reproduce a desired technique well but could not adapt this knowledge to unfamiliar circumstances is reported by Dreyfus [5]. There is also some suggestion that deep understanding can help in the retention of what is learned and confidence in the subject [7]. Fuson *et al.* [8] even attribute some students' dislike of mathematics as a subject to focusing the instruction merely on procedural knowledge.

Of course, science and business students are learning mathematics so that they can retain this knowledge and apply the techniques to unfamiliar scenarios in their home discipline and wider career. If such students are dissuaded from applying mathematics when necessary because they have forgotten the techniques, lack confidence to apply them, or even possibly have a dislike for the subject, then this is extremely problematic. Looking at it this way, then, the surface approach seems to be especially poor preparation.

My reading around this subject led me to be concerned that I was simply training my students in the mathematical techniques so they would acquire, as Dreyfus puts it, "the capability to perform, albeit much slower, the kind of operation which a computer can perform" [5, page 28]. Beyond the immediate experience, this investigation led me to believe that the approach explored during my Masters research was similarly flawed. If encouraging students to practice large numbers of out-of-context, little-varying, self-test questions is implicitly encouraging procedural, and therefore surface, learning, then this approach will discourage students' ability to retain and apply their mathematical knowledge.

3. Development of graduate skills

In 2009 I was to give a module for second year mathematics students which aimed to use mathematical project work to develop graduate skills, including time management, working in small teams, and communicating using reports and presentations. These aims, including a syllabus which did not intend to develop any particular mathematical topic, would require a very different approach to assessment.

Beevers and Paterson [2] describe "key skills" as "what is left after the facts have been forgotten" (page 51). Challis *et al.* [3] define a subset of key skills as "transferable" (page 80) and say that, in addition to academic knowledge, professional mathematicians require these skills to "use their knowledge effectively" (page 89). They say it is "incumbent on us, as teachers, to help our students to learn and develop these skills" (page 80). Lowndes and Berry [14] agree, saying that employers have "voiced their perceptions/criticisms that students/graduates are technically competent but lack professional skills, awareness of business issues, communication skills [and] problem solving skills" (page 20). There is clearly a need to develop these skills, but how is this achieved?

Hibberd [10] notes that "much of the teaching and learning in an undergraduate mathematics curriculum is provided by traditional lectures and problem workshops and assessment is dominated by examination" (page 5). This view of assessment of undergraduate mathematics in the U.K. is well supported by the findings of Iannone and Simpson [11]. MacBean *et al.* [15] note that "many people" view mathematics as a subject in which "something is either right or wrong" and thus it is "difficult to discuss or debate and . . . not open to differing opinions" (pages 1–2). This sort of teaching and assessment, and this view of mathematics, is well suited to short problem questions with well-defined correct answers of the sort that might be marked by computer.

Hibberd [10] suggests that these teaching and assessment methods are "strong" for "the attainment of knowledge" but make "more limited contributions to other elements" (page 6). Thomlinson *et al.* [23] recognise that e-assessment, with its "rapid feedback", can "promote engagement" in the first year of a degree, but that the use of closed questions required for rapid computer marking limits the potential to develop graduate skills (page 126). If widely used methods limit graduate skills development, is there a kind of assessment that is more suitable?

Waldock [24] argues that graduate skills can be developed by using alternative methods of assessment that encourage skills development alongside mathematical content, in a way that traditional assessment methods do not. Reporting on interviews with senior staff in U.K. university mathematics departments, Iannone and Simpson say that "some justified alternative forms of assessment as more realistic of the kinds of tasks students would encounter in later employment" [11, page 13]. Specifically, Hibberd [9] recommends that group project work can "[lead] students into a more active learning of mathematics, and an appreciation and acquisition of associated key skills" (page 159). A case study of Iannone and Simpson supports this, reporting the move away from examinations towards more project work at one U.K. university mathematics department as part of a drive to offer "the development and assessment of a wider range of skills" [11, page 8].

Traditional methods of assessment, using short problems with well-defined solutions, are well suited to use of e-assessment and computerised marking but less suited to the development of graduate skills. Challis *et al.* advocate that the development of transferable skills "should be embedded in the mathematics curriculum" [3, page 80]. Otherwise, they say, skills-based assignments risk being seen as "an 'add on' " rather than "an integral part of a mathematician's life" [3, page 90]. It seems that the approach taken in my Masters research, involving automated marking, is particularly at odds with the objective of embedding graduate skills development throughout the degree programme.

4. The pattern of the technology enthusiast

In 2009 I began working to support the mathematics curriculum through technology in a U.K. university mathematics department. Having been concerned that my e-assessment system may encourage surface learning and preclude the type of assessment that most favoured the development of graduate skills, my experiences in this role most of all made me question my 'wide-eyed' approach to using technology.

Often, technology is introduced out of general enthusiasm. I certainly saw that in myself and others during this role, and it lay at the heart of my Masters dissertation project. Apart from my own experience, I have met a number of technology enthusiasts and I have heard some give several seminars on projects that seem to exhibit the same approach: This looks interesting, let's try it and see what it can do; we can worry about what we are trying to achieve later.

I became involved with a project to conduct whole class quizzes through the use of response system technology (sometimes called an electronic voting system or 'clickers'). Audience members enter individual answers to questions via a remote device and these responses are displayed collectively to the group. This technology is thought to bring two-way communication in large lectures and provide a beneficial active learning opportunity to every member of the audience [22]. We used the technology in a large introductory applied mathematics module for regular quizzes to encourage students to keep up-to-date with lecture content and not simply save it all up to revise at the end. Each quiz was conducted, answers were given in class and students were encouraged to view worked solutions on the web later.

The lecturer felt that the technology was useful, and he received informal positive feedback from students. This encouraged him to plan to repeat the process the following year. An evaluation of students' reported use of the feedback they received during quizzes, however, suggested that the technology was only benefitting those students who were more likely to engage in any case [1]. Essentially, students who reported that they were encouraged by the quizzes to review module materials said that they kept up-to-date equally well with other modules where clickers were not used. Students who were not encouraged to engage were struggling to keep up with this and other modules equally.

Studies which reported a positive benefit for students were those that used clickers to drive an active change in teaching practice [6, 4], while those reporting no evidence of benefit were controlling for other factors, such as teaching and learning method, when introducing the new technology [12, 13]. The technology introduction in our experiment was not accompanied by an educational change, such as Crouch and Mazur's peer instruction driving a more active style of learning [4], and so the findings of the evaluation should perhaps not have been a surprise.

This technology was applied more or less in isolation, without driving a change in educational approach. It took time in class and effort on behalf of the lecturer and students, with positive effect on engagement with module materials, the stated goal, only indicated by students who self-reported as being more likely to engage anyway. Despite the positivity of the lecturer and the students he spoke to, an uncritical, unchanged repetition of use of the technology could be unhelpful or even detrimental. Use of the technology did provide the lecturer with valuable data about what the students did and did not understand in the form of their answers. If that is an acceptable goal, and the downside of time taken in class an acceptable price to pay, then the technology introduction may have been a success. As the desire was in fact to improve student engagement, and ultimately student learning, questions ought to be asked about implementation before the technology is used again. Learning to connect plans for technology implementation to clear educational goals and later evaluate against those goals is an important step that was missing from my Masters dissertation.

5. Discussion

At the start of this process I was a naive enthusiast willing to apply technology simply to see what can be done. Through an investigation of teaching methods to develop deep learning I came to worry that using e-assessment to generate large numbers of out-of-context, little-varying, self-test questions might give students the wrong message about the aims of assessment and encourage surface learning. This mode of learning can be detrimental to students because without understanding, they may not be able to apply techniques to unfamiliar circumstances and might struggle to retain what they have learned. Through designing a group project task to develop graduate skills I came to understand that producing graduates equipped for the challenges of life requires more complex tasks, and not just problems which are unambiguously right or wrong, to be embedded throughout the curriculum, limiting the effective range of e-assessment using automated marking across a degree programme.

Through investigations into learning technologies, I came to understand the pattern of the technology enthusiast and to recognise this in myself. This is where the naivety of my earlier approach is laid bare. A new technology is introduced, perhaps without a particular aim and fuelled by individual enthusiasm. This then receives positive feedback from those students who used it, perhaps masking disengagement by a silent minority who are disadvantaged, which in turn fuels further uptake of the technology.

Actually, to expect an automatic improvement of student learning simply by replicating a current approach using technology is not encouraged by my experiences. Technology introduction ought to be put in a context of educational need and implemented accordingly. Educational technology may not produce a benefit simply by its introduction, but a benefit may derive from a change of approach driven by the use of the technology. Approaching a curriculum development without considering potential educational need seems to me, now, to be a thoughtless approach. As such, a technology intervention should follow one of two patterns: to drive a change of practice which is beneficial to student learning or to replicate a current approach more efficiently without detrimental effect and with no expectation of effect on student learning, perhaps in order to release staff time for another activity to positively influence student learning.

The National Council of Teachers of Mathematics statement on "Technology in Teaching and Learning Mathematics" broadly supports this position. This recognises the value of technology in supporting and advancing "mathematical sense making, reasoning, problem solving, and communication", but says that this must be used "strategically" by teachers [17].

The approach taken when producing an e-assessment system for my Masters dissertation suffered from these problems: it was implemented with enthusiasm simply because it could be done and not to address any educational need; it encouraged surface learning; it precluded the sort of assessment that assists with graduate skills development; and, just because I was positive (and, given more time I may have found some students who were positive also) does not mean that the technology was benefitting anyone involved.

My focus in the years since I started my PhD project has shifted considerably away from enthusiastic implementation of e-assessment technology to one looking at the effect of using such technology and when and where it can be implemented to address an established need and produce an educational benefit. In general, my approach to using technology in education has become much more sceptical. I listen to people who say they are implementing some technology, or who ask me whether I am planning to introduce something, and my first question is: what is the educational need and how could technology address this better than the current approach? Otherwise, I won't waste everyone's time.

Acknowledgments: I am grateful to the editors and reviewers for their trust and patience during the review process, and for helping to improve the piece.

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