Getting to the CoRe – Exploring the use of technology to creatively support maths students' understanding of threshold concepts on lower-level maths courses.

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OUR PARTNERS

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About CfEM

Centres for Excellence in Maths (CfEM) is a five-year national improvement programme aimed at delivering sustained improvements in maths outcomes for 16–19-year-olds, up to Level 2, in post-16 settings.

Funded by the Department for Education and delivered by the Education and Training Foundation, the programme is exploring what works for teachers and students, embedding related CPD (Continuing Professional Development) and good practice, and building networks of maths professionals in colleges.

Abstract

This small-scale action research project sought to examine the potential of technology to support students, on lower-level maths courses, in navigating liminality (sticking points) in their fundamental knowledge of key topics. Our research aim was to use Content Representations (CoRes) to support mathematics teachers understanding of threshold concepts, their strategic decision-making about how to teach these, and to explore the use of technology to traverse states of liminality and manage troublesome knowledge.

Two iterations were completed at three Further Education Colleges in the North of England over a period of six months. The focus of iteration one was teachers' use of CoRes to identify threshold concepts and the introduction of technology, through online games, to support students' understanding. The second iteration focused on modification of the CoRe to support the use of technology as a pedagogical tool with an emphasis on delivery of learning and student engagement rather than assessment of learning.

Data collection consisted of the completion of CoRes and semi-structured interviews by teachers, student questionnaires and a literature review. Analysis of CoRes provided an insight into teachers' identification and thoughts about threshold concepts. Semi-structured interviews allowed teachers to share a 'chalkface' view about their ideas and views regarding the use of CoRes and technology to support students. Analysis of literature provided a starting point and framework for the research.

Findings indicate that the use of games positively impacts on students' motivation, focus and achievement, suggesting their potential to help students traverse liminal spaces in mathematical learning. CoRes were considered to be a useful tool to support planning and reflection. An unexpected finding was that students admitted their attendance increased as a result of this approach. For teachers, satisfaction with software appears to be influenced by its ease of use and perception of effectiveness.

Evidence suggests that these games were able to trigger some key characteristics of Flow theory, resulting in increased focus, loss of self-consciousness and sense of time. The use of games in the maths classroom to generate Flow therefore merits further investigation, as there are implications for teachers of mathematics irrespective of the use of technology.

Contents

Background

Introduction

Lakes College is a General Further Education College delivering technical vocational education situated in West Cumbria. Over the past five years, the Centres for Excellence in Maths (CfEM) programme has been a mainstay in supporting maths teachers to explore what works for them and the college's whole college approach to teaching mathematics.

The FE and college sector has been fully engaged in a national post-16 mathematics policy of increasing graded outcomes within GCSE examinations for several years now, featuring multiple strands of funding, activity, and support to enhance maths attainment. The Centres for Excellence in Maths (CfEM) has been a prominent feature within this context, making a very positive impact upon improved examinations results. The Centres have benefited from an ongoing programme of funding support, networking and the sharing of good practices, and access to high quality, credible research into practice via the University of Nottingham.

The collected efforts of the college sector, including the work of CfEM, has had a direct positive impact on increasing 'pass' and 'above grade' outcomes for GCSE mathematics. Notwithstanding these year-on-year increases, overall levels of first-time resit pass in maths for the 16-18 cohort are nationally at a relatively low level, and currently under 50%. Consequently, there is still a need for continued improvement and development in all factors that are significant in enabling more young people to re-sit and pass national examinations in maths, and in further developing practice and CPD in proven approaches that have a positive impact.

The recently announced national Multiply programme within the Shared Prosperity Fund is a welcome development aimed at supporting adults with developing enhanced numeracy and basic skills within functional maths. We look forward to enhancing our maths delivery and support within this programme and enabling more adults to benefit from improved numeracy skills for work and life.

According to Linford (2019) the Department for Education attainment figures for maths from 2014 to 2018 show a steady improvement, for those aged 19, following the introduction of the Government's Condition of Funding rule in 2014. This policy requires students entering FE Colleges who have almost achieved a pass at GCSE (level 3 or grade D) to continue their study, offering them a second chance. If their achievement falls below level 3 or grade D, then colleges can choose whether to put students on a GCSE or Functional Skill. Where possible these students are streamed, falling into a 'near miss' or lower-level category. Our research focused exclusively on the lower-level category students.

Research Aim

Our research aim was to use Content Representations (CoRes) to support mathematics teachers understanding of threshold concepts, their strategic decision-making about how to teach these, and to explore how technology could be used as a mechanism to support students on lower-level maths courses to traverse states of liminality and manage troublesome knowledge.

The rationale behind the research topic was to improve the mathematical abilities of students on lower-level courses. These students, who often have had poor experiences at secondary school, are sometimes wrongly labelled as “academically lower level”, which is interpreted as a deficit in their intellectual capability when it is the subject level of material they are studying, not their abilities that is lower level. Students often internalise this label, believing themselves incapable of achievement. Our goal was to find innovative teaching methods using technology that would improve confidence and support firm understanding of topics key to maths mastery.

During initial collaborative discussions, we identified a common event, where students become ‘stuck’ attempting to grasp fundamental concepts to a topic’s understanding. These constructs, known as threshold concepts, are key principles that students need to have a firm understanding of to achieve mastery of a subject. Present in every subject specialism they have the power to transform understanding of a topic (Mayer and Land, 2003). However, before students can reach a point of understanding they often encounter ‘stuck’ moments, as they struggle to conceptualise and assimilate new concepts, this can last hours, days or months and is known as liminality. To successfully teach threshold concepts Breen and O’Shea (2016: 11) recommend that they should be “visited frequently and viewed from different perspectives”. Our belief was that the use of technology would allow us to do this.

Literature Review

In this chapter we define and review different types of threshold concept. We draw upon Schulman’s Pedagogic Content Knowledge to help understand differences between pedagogic practice and lower-level students’ understandings. We go on to consider some key requirements for the successful implementation of technology in the classroom that supports understanding of mathematical threshold concepts. A theoretical framework (TPACK) is reviewed as a tool to support understanding and inform CPD.

Threshold Concepts

Within each subject specialism there exists key concepts, which are so important that their mastery is ‘akin to passing through a portal’, resulting in transformational understanding of a topic or subject (Mayer and Land, 2003). These constructs, which exist in all subjects, are known as threshold concepts. In 2014, Sharples et al. identified threshold concepts as number nine of ten educational innovations with the potential to significantly change education, concluding that their value lies in their ability to provide deep and lasting understanding of complex concepts.

Threshold concepts vary in their nature from formal ideas within the discourse of a subject to everyday concepts or abstractions (Mayer, 2013) and can be linked to 'troublesome knowledge', a term developed by Perkins (1999) to distinguish four different types of problematic learning: inert, ritual, conceptually difficult and foreign knowledge.

Inert knowledge refers to knowledge which is known but used infrequently and requires prompts to bring it to mind. Mathematical examples are formulas, which appear in formal examination questions but are less relevant to everyday life and therefore seldom used, if at all, once examination is over. Ritual knowledge is knowledge that is part of a procedure or technique for a specific task. As such, it can result shallow understanding making it difficult to recall. Due to its specialist nature and lack of relatability to other subjects' ritual knowledge may become inert. Perkins (ibid) identifies the division of fractions rule, where it is necessary to 'invert and multiply to divide fractions' as an example of this type of knowledge. Conceptually difficult knowledge differs in that it requires additional information for it to make sense and may conflict with a student's usual approach. This type of knowledge may require unlearning of previous ways of thinking making it particularly challenging. It requires understanding of not only what to do, but the why it is done, and how it is connected other topics. Foreign or alien knowledge is particularly difficult presenting an atypical perspective that is unfamiliar to the learner. However, it must be noted that troublesome knowledge and threshold concepts are not always synonymous (Ross et al. 2010).

To be identified as a threshold concept Meyer and Land (2003) assert that the construct, regardless of subject area, must alter the way the subject matter is viewed, requiring the student to traverse what is termed a 'liminal state'. This is a state of perplexity, which may last some time, requiring students to move back and forth grappling with their knowledge until, free of previous misconceptions they shift from prior to new understanding.

Pedagogical Content Knowledge

Threshold concepts are key to the proficiency of a subject and are core to Pedagogical Content Knowledge (PCK), a term coined by Schulman (1986) to describe a blend of subject content knowledge, pedagogical knowledge, and context where learning occurs. PCK allows teachers to identify problematic concepts and focus on the best way to support students to grasp them. Key to this is an understanding of what makes a topic easy or difficult to teach. This can be identified using Content Representations (CoRes), which are in the form of a matrix with a set of key questions that the teacher answers to identify content essential for understanding of the topic being taught. This key content often contains threshold concepts, without which mastery of the subject would be impossible.

PCK is not new to mathematics, others have used it as a theoretical framework for their research (Depaepe et al., 2013; Venkat and Adler, 2014; Illyas, 2015; Gess-Newsome, 2015; Kadarisma et al. 2019). In 2008, the concept of Mathematical Pedagogical Content Knowledge (MPCK) was introduced in a Teacher Education and Development Study of Mathematics (Lo, 2020). MPCK consists of two key parts. Firstly, knowledge and instructional strategies including "analogies, illustrations, examples, explanations, and demonstrations". Secondly, knowledge of students' perceptions about mathematics. Lo (ibid) highlights researchers' specific interest in how teachers manage students' errors and misconceptions. This is a key component of PCK.

The initial impetus for our research came from discussions concerning difficulties encountered when teaching students on lower-level courses. Teachers perceive a clear dichotomy between their pedagogical practice and students' understanding; requiring significant input to implement numerous cycles of adaptive teaching, sometimes with limited success. The aim of this research is to use CoRes to support mathematics teachers' understanding of threshold concepts, their strategic decision-making about how to teach these, and to explore how technology can be used as a mechanism to support students to traverse states of liminality and manage troublesome knowledge.

The challenge of technology

Although digital technologies have the potential to improve mathematical understanding, they remain largely underused (Thurm and Barzel, 2020). Drijvers (2019) supports this assertion, stating that the challenge for teachers is the selection of digital tools and their subsequent integration into practice. This is echoed the findings of previous Centre for Excellence in Maths reports.

Olive et al. cited in Hoyles and Lagrange (2010) consider the challenge of using technology to produce innovative classroom practice referring to Piaget's theory of assimilation and accommodation (1970). Assimilation is the cognitive process of adding new information to existing understanding without significant change occurring. If the concept is forced to fit into an inflexible perspective a loss of intent may occur. Piaget claimed that to understand, it is sometimes necessary to adapt conceptual thinking. This is known as accommodation and occurs when new information challenges original thinking, requiring deconstruction and reconstruction to grasp its meaning. Olive et al. (ibid) propose that this is happening in mathematics classrooms where technology is being assimilated rather than accommodated inhibiting innovation. It could be argued that assimilation of technology has transpired as teachers are subject to the tyranny of outcomes with examination results dictating success limiting their capacity to update their teaching practice.

Drijvers (2015) examined six case studies to identify success factors, including the role of the teacher, and context and design when integrating technology into mathematics classrooms. This included a case study examining the use of mobile technologies. An example used was an outdoor Hybrid Reality Mobile Maths game involving the construction and destruction of geometric shapes played on a mobile phone. The authors deemed this a success, referencing Prensky's (2001) heuristic model for the design of engaging games. Specifically, Prensky identifies "...*clear rules and goals, outcome and feedback, conflict, challenge and competition, and interaction*" as key components to successful engagement. The game factor, in combination with the attractiveness of the device worked well. This is interesting as many students have access to mobile devices, although the quality of these vary as does access to data.

Drijvers (ibid) also recognises the importance of the teacher and their willingness to engage with theoretical models such as Mishra and Koehler's (2006) Technical Pedagogical Content

Knowledge (TPACK) that can be used to support the integration of technology into teaching. TPACK builds on PCK by adding technology to subject specific knowledge helping teachers to identify how digital tools can be used to support subject specific content using pedagogical techniques. It also requires consideration of how technology can be used to support students and build on this. The TPACK model is also valuable as it can act as a device to evaluate teachers' grasp of digital pedagogy, which can be used to inform continued professional development.

Conclusion

The review of literature reveals a synergy between threshold concepts, troublesome knowledge, Pedagogical Content Knowledge, and Technical Pedagogical Content Knowledge. These relationships will be used to support the research approach. The work of Mayer and Land (2003) is key to teachers being able to differentiate between Perkin's 'troublesome knowledge' (2009) and threshold concepts since threshold concepts are identified through their ability to transform the way in which a learner understands a topic. This definition will be used to identify threshold concepts for the purposes of this research. Our aim is to help teachers identify and teach threshold concepts, using CoRes as a reflective tool to support proficiency in modifying and/or adapting their teaching using technology as a vehicle to negotiate liminal states. It will also explore challenges faced by mathematics teachers when integrating technology into their lessons and gather students' opinions of its usefulness in supporting learning. This will lead to recommendations to support the CPD of mathematics teachers.

Methods

This small-scale action research project was carried out in three Further Education (FE) colleges over a period of six months. Two of the colleges were General FE colleges. Both were selected because they were similar in profile and inclusive in terms of their intake, curriculums, and geographical makeup, with communities exhibiting varying degrees of social deprivation and unemployment. Relatively large numbers of 16–18-year-olds leave school with poor attainment at GCSE, and a negative disposition towards GCSE maths, which presents considerable challenges to each college. There are pockets of deep and long-standing deprivation throughout both areas, with 11 – 16 results at or below national averages for the past several years. Halfway through the project at the beginning of iteration two, a land-based college outside of county, joined the project. The third college was added as a 'wild card' to see if what we were experiencing might be generalisable.

The research set out to identify threshold concepts in relation to topics taught to students on low level courses, and to consider how technology could be amalgamated to support delivery and provide students with a different viewpoint that could be revisited. We wanted to work with teachers whose classes were classified as 'low level' and encompassed a diverse range of students, including those with support needs, and who were committed to improving their practice.

Three teachers were self-selected, volunteering to be involved in the research. The total number of participants was 95. Comprising the following:

- *Aardvark College* - 3 classes with 21 students.
- *Iguana College* - 6 classes with 58 students.
- *Narwhal College* - 2 classes with 16 students.

Although we originally planned three iterations, two were completed (see page 11). This was due to Covid impacting on teachers through cover requirements and time taken to obtain finance approval for software licences. The first iteration focused on the identification of threshold concepts. Teachers worked collaboratively to establish common issues and misconceptions to identify threshold concepts. The second iteration focused on technology and pedagogy, requiring exploration of existing thinking around technology as a tool to support learning, rather than as a formative assessment tool. At the end of the first iteration the CoRe was modified to include 3 questions with a focus on the use of technology.

These questions were:

1. How can this concept be shown / supported using technology?
2. What technology could be used to present key ideas in different ways?
3. How can we use technology to work collaboratively on this concept?

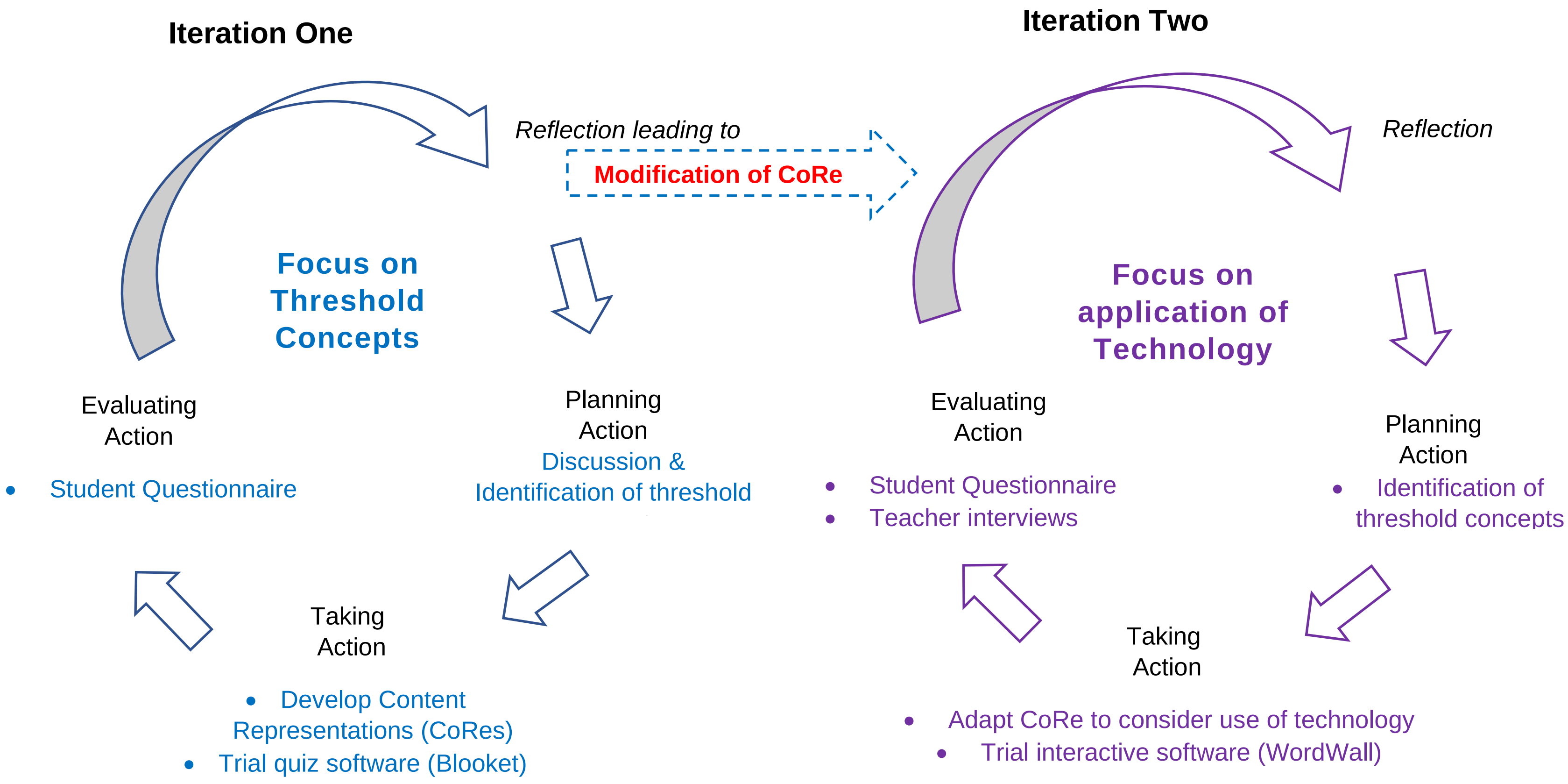
Mixed methods were used to collect data. However, in keeping with an action research approach predominantly qualitative data was collected through six Content Representations (CoRes) and three semi-structured teacher interviews. It was important to the research to explore how maths teachers identify threshold concepts and the strategies they use to teach them. Therefore, teachers individually completed CoRes. To ensure parity we agreed the topics that each CoRe would target, and these same topics were taught simultaneously at each college. Three twenty-minute semi-structured interviews of teachers took place at the end of the research, one face to face and two using Microsoft Teams. These gathered teacher's opinions about the use of CoRes to support planning and as a tool to identify threshold concepts. Views about the application and user-friendliness of technology were sought.

This data was supplemented by quantitative data collected through two attitudinal questionnaires to gather students' views. To obtain a truer reflection and avoid students providing answers they believed the teacher was seeking, questionnaires were anonymised and completed online to provide an unbiased sample. In keeping with ethical values, participants were fully informed about the purpose of the research and made aware of their right to withdraw at any point.

The initial iteration questionnaire sought to elicit students' responses using a five-point Likert scale and, following discussion, response options were 'translated' into student-friendly statements. Responses ranged from "*I'm okay I've got this*", to "*I can't do this*", and "*Definitely*" to "*Never*". All statements were linked to the use of technology to support maths. Example statements from the questionnaire included: "*Using technology makes me better at maths without realising it*", "*When I use technology in maths my maths scores are better*". We also included reversed questions such as “*Technology does NOT help me in class*”, and “*Using technology in maths makes the lesson confusing*” to address response bias.

Research Questions in relation to Methods Used

Research Question	Methods Used	Data Sources	Justification
1. How can technology be used to support the creative delivery of maths to students on low level courses?	• Completion of Content Representations (CoRes) • Teacher semi-structured interviews	• CoRe documentation • Teachers	Analysis of CoRes created by teachers provided an insight into their thoughts about what threshold concepts existed within the topic areas and what they needed students to master to succeed. Semi-structured interviews allowed teachers to share their ideas and views about the use of technology in the classroom.
2. What is the impact of the use of technology on delivery of threshold concepts for students studying lower-level maths courses?	• Student questionnaires • Teacher semi-structured interviews	• Students • Teachers	Student questionnaires allowed us to gather opinions quickly and anonymously from participants. Semi-structured interviews provided a teacher view from the ‘chalkface’.
3. What support/ understanding of digital pedagogy do teachers require to effectively use technology to teach mathematics?	• Literature review • Completion of Content Representations (CoRes) • Teacher semi-structured interviews	• Literature Review • CoRe documentation • Teachers	Analysis of literature provided a starting point. Modified CoRes identified teacher’s thinking around the application of technology. Semi- structured teacher interviews enabled the triangulation of findings.



Action Research Cycles adapted from Coghlan and Brannick, 2014

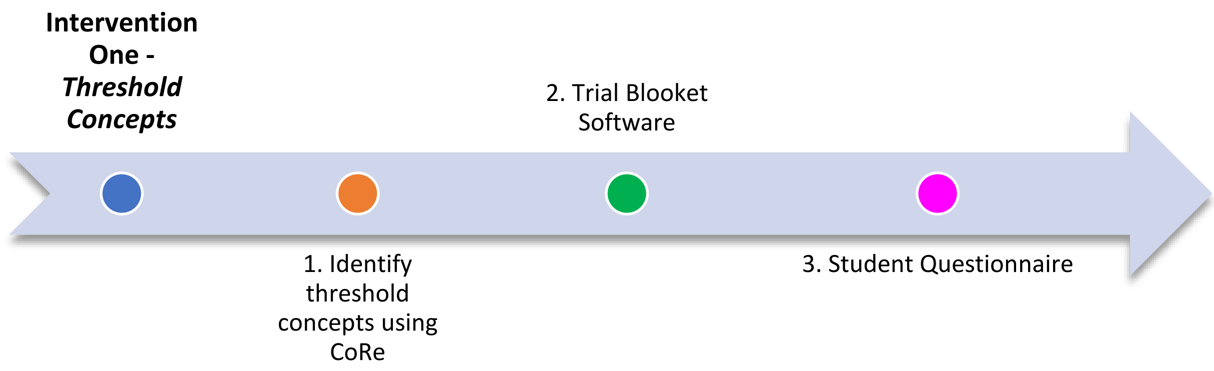
Findings

Interventions

Two interventions were completed, both running over a period of 8 weeks. The first intervention took place from week beginning 18th October to week ending 17th December excluding October half term. Iguana and Narwhal colleges collaborated on this. A third college had been invited to join the project but was unavailable. The research began with a collaborative discussion focusing on teaching and learning including difficulties encountered when teaching lower-level courses. This approach seemed particularly pertinent because it offered teachers an opportunity to reflect and share what works in their practice, and identify familiar sticking points encountered, with a view to problem solving. During the conversation it became clear that there was a clear dichotomy between their pedagogical practice and students' understanding when they became stuck; requiring significant input to implement numerous cycles of adaptive teaching, sometimes with limited success.

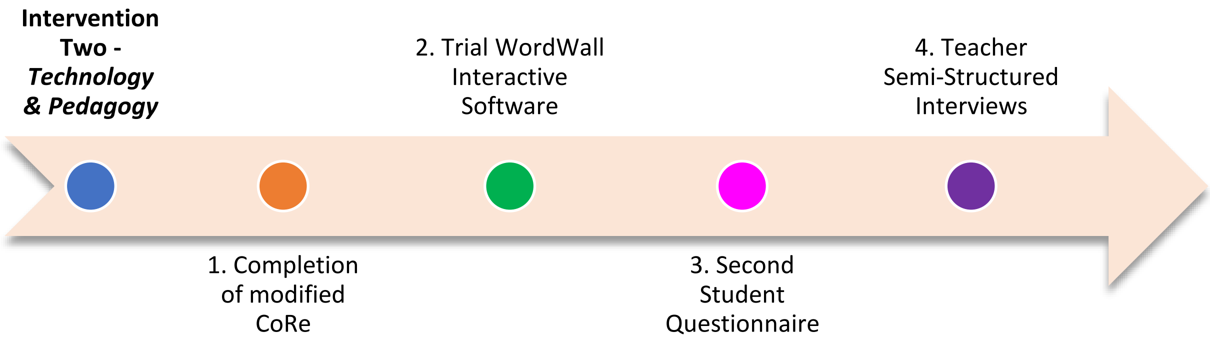
As a group we identified key topics that could be taught simultaneously. Ideas were then captured using Content Representations (CoRes). CoRes are in the form of a matrix with a set of seven key questions the teacher answers to identify content essential for understanding of a topic. All three research teachers completed these individually and shared them via a Padlet. We then considered how technology could be used as a mechanism to support learners to traverse states of liminality when they become 'stuck'.

Our choice for this project were online games that would engage and ignite the learners' enthusiasm but were user friendly for both the teacher and the student. We identified two online resources. A game, Blooket, which is a modern classroom review game, where learners answer questions and compete against each other earning points and coins which they can spend and lose along the way, and WordWall, which has a range of customisable and pre-populated interactive game templates for teachers to modify and use.



The first intervention took place using Blooket at Iguana and Narwhal colleges. A total of 74 students took part. Iguana College used Blooket at the beginning of lessons as either a starter activity or at the end as a plenary activity to consolidate learning. Links on Teams provided further opportunity for students to engage outside of the classroom. Narwhal College used Blooket every lesson, as either retrieval practice, a warmup activity or to pre-empt skills that would be required for the lesson. Time limits were set for questions to add challenge. At the end of the eight-weeks all students were asked to complete a questionnaire to ascertain views about the use of Blooket as a tool to support learning.

The second intervention took place week beginning 7th February and ended 8th April (excluding February half term). Aardvark College joined the research in March to see if findings might be generalisable. We agreed a focus for the amended CoRe adding three questions related to the use of technology. CoRes were then completed individually and shared using Padlet.



Iguana college used WordWall to create interactive exercises which were used as revision and to check learning using quizzes, match up and group sort activities. Topics included shape identification, times tables, and division & multiplicative reasoning. Narwhal's topics included non-calculator practice, fraction decimal percentage and equivalences. Exercises created included Whack-a-mole exercises, where students click on the moles with the correct answer to make them disappear, random wheels of questions, open the box and group sort exercises. Due to time restrictions Aardvark college focused solely on division skills using Whack-a-mole, find the match and maze chase. Following the intervention, students were asked to complete an attitudinal questionnaire to obtain opinions towards the use technology to teach maths and its usefulness. Finally, semi-structured interviews were conducted with three teachers to gain insight into the use and effectiveness of CoRes and technologies used.

Results

The data indicates that both students and teachers were positive about the use of technology to support learning. CoRes were considered an asset to support lesson planning, sequencing of topics, reflection, and strategizing.

Following the research teachers reported the impact on their cohort results. At Narwhal college 90% of the cohort who took part in the research showed a 5-mark increase. For Iguana college improvement was more noticeable with all students increasing marks from 5 up to 40. Aardvark college, who joined the project later, reported increased attendance and engagement but no notable change in marks. It is important to note that despite encouraging results from Narwhal and Iguana colleges, exam grades did not always increase, due to the nature of mark boundaries.

Documentation – CoRes

Comparative analysis was carried out on CoRes to identify similarities and differences between ideas about teaching key topics and to find agreement about identification of threshold concepts. The way the CoRe was structured split teachers thinking into two categories, curriculum, and teaching. Following completion of iteration one, modification of the CoRe took place, resulting in an additional category – technology, for iteration two.

The ability to identify threshold concepts is significant as teachers need to plan when students will encounter them, which tools/strategies will be used to deliver them, and where in the teaching scheme they will be revisited or required. Initial indications of teachers starting points in relation to identifying threshold concepts are that they are at a developing stage. Teachers were eager to explore this idea but found it challenging to engage with. During iteration one, analysis showed a tendency to focus on troublesome knowledge (Perkins, 1999) which is problematic but often not transformative. However, iteration two showed progress with two big ideas which were transformative. Later during interviews, when asked to explain their understanding of threshold concepts, teachers struggled but were able to articulate key concepts from the CoRes matrix.

All teachers were supportive of the use of CoRes to assist with planning and reflection, agreeing they would use them in the future.

> *“I actually found it [CoRe] very useful having the topic broken down into a thinking pattern. It allowed you to look at things in a different way each time, especially when we were coming up with ways to overcome those issues*.” Tutor Narwhal College

> “*Really helpful, the matrix was amazing because it helped with reflection. I referred back to the matrix to help me plan the activities on WordWall*.” Tutor Aardvark College

Teachers felt using CoRes allowed them to view key topics from different perspectives and identify misconceptions. This is important as it enables them to plan for and point out potential issues to students in advance, so they become more aware of difficulties in mathematical knowledge development. CoRes also supported reflective practice allowing teachers to think through and plan strategies to overcome problems. One teacher however voiced concern about their capacity to add to teachers' workload.

Three questions were added to support the use of technology during iteration two, these revealed gamification as the preferred way of engaging learners. This is perhaps unsurprising since games were being used for the research and none of the teachers at the beginning of the project considered themselves to be confident with technology, indicating knowledge about different digital tools was limited. Quick games that could be completed on a variety of mobile devices and non-timed engaging games suiting many types of working were identified as useful, demonstrating inclusive thinking. Using technology to work collaboratively was considered by Narwhal college from the perspective of sharing with colleagues using a Padlet, while Aardvark and Iguana colleges focused on students with competitions and league tables to support motivation.

Comparison of CoRes found that teachers focused on three aspects: what students needed to do, what the teacher needed to do, and missing underpinning knowledge which needed to be addressed. Similar thinking was apparent between teachers however, more detailed answers would be required to fully explore this. A typical example was responses given for the identification of misconceptions and difficulties or limitations when teaching topics. These were weighted towards what the student needed to do, indicating that teachers are aware of common difficulties, however, because there was no indication of the types of strategies being used to address these, pedagogical comparisons could not be made. The hope is that as the teachers develop familiarity with CoRes, they will progress to making connections between what students need to do, which teaching approaches might achieve this and how to address gaps in knowledge.

Teachers – Semi-structured interviews

Semi-structured interviews revealed that teachers in this project chose to use resources (Blooket and Wordwall) in diverse ways to support student learning. These choices appeared to be based both on the teacher's confidence to use the technology, the time required to learn how to use it and set it up, and how effective it was judged to be in supporting learning.

Ease of use appears to be important. As technology advances applications are becoming much more user friendly and easy to modify. This reduces the amount of time teachers require to learn how to use software and enables them to quickly create exercise banks that can be repeatedly accessed inside and outside of the classroom. Although this does not necessarily improve digital skills, teachers were impressed with the ease and speed at which they could create professional looking exercises.

> *"I wouldn't say my technology skills have improved but it has reignited my love for technology. We were using things that were so fiddly and difficult to use whereas these are so much easier and user friendly."*
> Tutor Narwhal College

However, user-friendliness does not always guarantee engagement when there are competing pressures. A teacher from Iguana college commented that they had less time to use Wordwall (second iteration), which required customisation of game templates, due to the time of the year.

Teachers' views about student learning and technology were an important part of the decision-making process about how best to use it to support learning. This added an additional layer of complexity to the process as it required them to bring together knowledge of the syllabus and knowledge of the software tool to consider how it could best be utilised to support threshold concepts. There was evidence that these teachers had thought carefully about the effectiveness of technology as a teaching tool, considering how it could be best used to support their students mathematical learning without becoming a distraction and negatively impacting on results. This is exemplified in the following quote:

> *"I've really had to think about how it's supporting their learning and isn't just a gimmick that soaks up time for both them and me and doesn't teach them anything because at the end of the day we are still accountable."*
> Teacher, Aardvark College

An unexpected finding is that the use of games appears to have supported reflective skills for more hesitant students who seem to have benefitted from watching their more confident peers.

> *"Learners become far more reflective when you use it as a game. For example, when I put the whack-a-mole game on the interactive board, those watching would identify the pattern and that started a discussion in an informal manner."*
> Teacher, Narwhal College

Teachers also detected subtle shifts in their role while using technology. These included facilitator, interpreter, and technician. As a result of using technology, they are now much more likely to hand over learning to their students and reflect on its effectiveness.

> *"I have a completely different job if you will. I'm much more of a facilitator and erm tech, and less hands on in a way. I mean I explain the task and what they need to do if needs be. But it's given me the time to really observe who gets it and who doesn't and whether it's working the way I wanted…"*
> Teacher, Aardvark College

Asked about the impact of using technology teachers reported improvement in resilience, focus and concentration.

Students – Questionnaire responses

Results from student questionnaire one revealed that the majority of learners believed playing games had improved their mathematical skills (82%), and mathematical confidence (87%). It is important to acknowledge at this point that the response rate to the questionnaire was low at 30%. Nonetheless, this is significant because confidence plays an important part in the successful traversing of threshold concepts and can be linked to self-efficacy, an assessment of an individual's confidence in their ability to successfully achieve a given task (Hackett and

Betz, 1989: 262). Felton (2014) confirms this belief stating that to permanently cross a threshold you have to believe that you "belong on the other side".

An unexpected finding was that 48% stated using games had improved their attendance, suggesting that familiar pedagogical approaches may be less appealing for students on lower-level maths courses, and there is a greater need to innovate. At the beginning of the project there were some concerns about students' ability to access digital devices outside of the classroom, therefore interventions were in class with an option for students who had suitable devices to continue their use outside of class. It is possible that those students who had no or limited access to digital devices at home enjoyed the opportunity to learn through gaming, alternatively they may have preferred the opportunity to work collaboratively with peers.

Responses for the first questionnaire were positive with 74% of students stating they preferred to use technology in class. A large majority of students (69%) felt the lesson passed quickly when using technology, and over half (56%) reported their maths scores improved. These encouraging responses led to questions about why these students should be so positive. Further analysis indicated markers for Flow theory (Csikszentmihalyi, 1975), a common component of game design, which balances challenge and skill level to produce a state of intense focus. A follow up questionnaire was designed with questions based on The Flow Questionnaire by Mihalyi Csikszentmihalyi to corroborate this.

Results from the second questionnaire matched findings in the first, identifying some key characteristics of Flow Theory, which could be linked to both cognitive and emotional Flow. Key to Cognitive Flow is challenge, enabling skills to be stretched with clear goals so the person knows what is required of them, and feedback to support progress. Emotional flow includes complete focus on the task, a loss of self-consciousness, and loss of a sense of time. All of these were present in the questionnaire and tutor feedback. As the questionnaire was anonymous it was not possible to know if the same students responded. Again, the response rate was low at 29%.

Data analysis revealed that 83% of these students felt the lesson went quicker when online maths games were used and 89% said they were totally involved in what they were doing. These are strong indicators of a state of Flow, where there is total focus and time passes rapidly. Over two thirds (68%) of the sample stated they enjoyed the competitive nature of online maths games, which includes clear goals and feedback on actions. One teacher corroborated this commenting that they had "…*underestimated how much they like a good piece of healthy competition*."

These students strongly agreed that when maths games were used, they were totally involved in what they were doing (89%) with 72% stating that they felt they concentrated more on maths than normally when playing games. This was observed by their teachers, all of whom commented on improved concentration and focus. "*They are much more focused on the task. I think it has to do with the software we are using they are both very engaging."* This state of heightened focus may well have contributed to the conclusion, by over half of students (56%), that using games made them better at maths without realising it.

Conclusions and Recommendations

Conclusions

This project demonstrates the potential of technology to create a dynamic learning environment in the maths classroom for students on lower-level courses. Findings indicate that the use of these games had a positive impact on students' learning, signifying the potential to support students through liminal spaces in mathematical learning. Students were able to practise mathematical functions, build resilience through repetition, and use reflection to identify patterns analysing their significance through discussion. Teachers and students reported improvement in engagement and concentration during lessons.

While CoRes give the impression of being deceptively simple to use, their true success hinges on the teacher's ability to understand and accurately identify threshold concepts. This can be a difficult idea to grasp. Analysis of CoRes revealed a focus on three characteristics: student needs, teacher needs, and gaps in knowledge. Teachers were able to identify common difficulties; however, at this early stage of use, there was no linkage to strategies which might address these misconceptions. Although CoRes were considered to be extremely useful as a lens to support planning and reflection, it was acknowledged that they could become onerous if required in addition, rather than in preference, to other planning paperwork. Modification of the CoRe during iteration two provided a focus on the use of technology, allowing teachers to concentrate on the best ways to use it to support learning and avoid negative impact. Drijvers (2015) identified teacher willingness to engage with theoretical models such as TPACK as a significant feature of successful use of technology in the classroom. The inclusion of three technology questions to the CoRe for the second iteration supported teachers to reflect on digital pedagogy.

For these teachers, selection of software applications appears to be heavily influenced by its ease of use, teacher confidence and perceived effectiveness. This allows them time to concentrate on the topic being taught, rather than fret about the time required to learn a new application or address technical issues. To further support teachers, it would be useful to provide a mechanism where digital tools to support teaching and learning can be researched, pre-tested and recommended to curriculum staff on their basis of ease of use.

An unexpected finding was the students' disclosure that their attendance had increased as a result of this approach. It appears that the use of games is an effective way of capturing and holding interest through the mechanism of challenge, clear goals, and feedback, all of which can be related to Flow theory. However, for future development it is important that teachers ensure students experience a variety of different games and technologies to maintain their enthusiasm and prevent lassitude.

The research has implications that extend beyond the use of games to engage learners. Indications are that the use of games in the classroom to generate Flow warrants further investigation, which may have significant implications for teachers of mathematics, regardless of the use of technology as a trigger.

Recommendations

Following analysis of findings these are the recommendations for managers, leaders and teachers.

Managers and leaders should:

1. Provide time to allow teachers to develop CoRes as part of their planning. This will support teachers with identification of threshold concepts and enable them to reflect upon the best strategies and classroom approach for their students.

2. Provide a suitably qualified person, to assist in the resourcing of a variety of digital tools for teaching and learning. This person should research, test and make recommendations on the basis of ease of use.

3. Provide teachers with time and a safe digital space to try new technologies.

4. Ensure Wi-Fi connections are robust and access to digital technology and support are available when teaching is taking place.

5. Plan CPD to support teachers' digital confidence and competency. Jisc's Digital Capability Framework and The Education and Training Foundation's Digital Teaching Professional Framework could be used to establish starting points. A range of free digital CPD such as Microsoft and Google certifications could be used alongside the sharing of good practice.

6. Consider how maths lessons are structured. It is recommended that these should include a digital element, in most lessons, to support practice and reflection. Particular attention should be paid to those lessons involving the mastery of threshold concepts.

Teachers should:

7. Use CoRes to raise student awareness of commonly encountered difficulties in mathematical knowledge development. This will support self-efficacy and resilience in enabling students to make progress towards mastery of threshold concepts.
8. Ensure students experience an assortment of different games and technologies to maintain their enthusiasm with a focus on challenge, clear goals, and feedback.
9. Develop an open-minded approach to using technology in the classroom. Identify gaps in their digital knowledge and access CPD, evidencing progress, to improve confidence and competency.

10. Use carefully selected digital games to explore vocabulary and meaning as well as mathematical operations.

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Appendix/Appendices

Questionnaire 1

CfEM 2021-2022 Evaluation of maths

1. How confident are you using technology?

- ◯ I'm okay I've got this
- ◯ I am not bad at this
- ◯ I could probably do this but may need help
- ◯ I'm not sure about this
- ◯ I can't do this

2. When it works I feel comfortable using technology in maths lessons

- ◯ I'm good at using technology in maths lessons
- ◯ I'm okay at using technology in maths lessons
- ◯ I can use technology in class but may need help
- ◯ I have problems using technology in maths lessons
- ◯ I can't use technology in maths lessons

3. Technology DOES NOT help me in class

- ◯ Strongly Agree
- ◯ Agree
- ◯ I don't know
- ◯ Disagree
- ◯ Strongly Disagree

4. Using technology makes me better at maths without realising it

- ◯ Strongly Agree
- ◯ Agree
- ◯ I don't know
- ◯ Disagree
- ◯ Strongly Disagree

5. Using technology makes the lesson more interesting

- ◯ Definitely
- ◯ Sometimes
- ◯ It depends
- ◯ Not really
- ◯ Never

6. Using technology in maths lessons makes the lesson confusing

- ◯ Definitely
- ◯ Sometimes
- ◯ It depends
- ◯ Not really
- ◯ Never

7. When I use technology in maths lessons my maths scores are better

- ◯ Definitely
- ◯ Sometimes
- ◯ It depends
- ◯ Not really
- ◯ Never

8. I feel the lesson passes quicker when we use technology

- ◯ Definitely
- ◯ Sometimes
- ◯ It depends
- ◯ Not really
- ◯ Never

9. Using technology in maths lessons makes me feel stressed

- ◯ Definitely
- ◯ Sometimes
- ◯ It depends
- ◯ Not really
- ◯ Never

10. I prefer to use technology in my maths classes

- ◯ Definitely
- ◯ Sometimes
- ◯ It depends
- ◯ Not really
- ◯ Never

Submit

Questionnaire 2

CfEM 2021-2022 Evaluation of maths

1. How confident are you using technology?

- I'm okay I've got this
- I am not bad at this
- I could probably do this but may need help
- I'm not sure about this
- I can't do this

2. When it works I feel comfortable using technology in maths lessons

- I'm good at using technology in maths lessons
- I'm okay at using technology in maths lessons
- I can use technology in class but may need help
- I have problems using technology in maths lessons
- I can't use technology in maths lessons

3. Technology DOES NOT help me in class

- Strongly Agree
- Agree
- I don't know
- Disagree
- Strongly Disagree

4. Using technology makes me better at maths without realising it

- ◯ Strongly Agree
- ◯ Agree
- ◯ I don't know
- ◯ Disagree
- ◯ Strongly Disagree

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