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Online Resource Platform for Mathematics Education

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***Abstract*—Engineering education is facing many challenges: a decline in core mathematical skills; lowering entry requirements; and the diversity of the student cohort. One approach to confronting these challenges is to make subject content appropriate to the communication styles of today's student. To achieve this, a pedagogical shift from the traditional hierarchical approach to learning to one that embraces the use of technology as a tool to enhance the student learning experience is required. By including the student as co-creator of course content, a greater sense of engagement is achieved and a change to one where students become agents of their own learning is realized. This active learning constructivist approach shifts the focus from content delivery by the lecturer to active engagement with content by the student and in doing so provides an environment of achievement and ownership which empowers the student and increases self-efficacy. The online platform comprises a set of multiple choice questions focused on core mathematical concepts. The quizzes are constructed to adapt to student responses with custom video feedback created by their peers. This paper outlines the methodology followed and provides results of its evaluation in terms of student's perceptions.**

Keywords—engineering mathematics; active learning; student engagement; student learning experience; graphic tablets; transformative technologies; transferrable skills; first year experience

I. Introduction

The importance of mathematics in engineering education particularly for those students studying a STEM (Science, Technology, Engineering, and Mathematics) related discipline is widely acknowledged. Educators of engineers are facing many challenges in higher education with particular concern being focused on a decline in the core mathematical skills [1] [2] and lack of preparedness of students entering engineering programs [3] [4]. Evaluation of mathematical competencies using a standard maths diagnostic test (MDT) has shown that many students are lacking in core mathematical skills [5] [6]. A number of approaches taken to reverse these concerns are documented in [7].

This paper outlines a study undertaken in the College of Engineering and Built Environment at the Dublin Institute of Technology to create an on-line platform of resources which allows first year engineering students to consolidate and reinforce core mathematical concepts required to succeed in engineering programs. The use of technology to enhance the first year learning experience by increasing student motivation, engagement and attainment is explored. By including the student as co-creator of course content, a greater sense of involvement is achieved and a shift from the traditional passive role to one where the student's become agents of their own learning is realized.

The methodology followed in the creation of the online platform is outlined and results of its evaluation in terms of student's perceptions are provided. The results show a positive attitude towards the use of technology and the provision of a variety of methods instead of a traditional approach to tutorials.

II. Irish Educational System

A. Entry to Higher Education in Ireland

The Irish educational system can be described as a 4-tier structure encompassing pre-school, primary, secondary and third level sectors. Attendance at pre-school is at the discretion of the parents, however all citizens of school-going age must attend formal education up to the age of 16 years. A significant proportion of students who complete their second level education continue their studies at further education centers, third level institutes or universities [8]. The uptake in the study of STEM related disciplines has steadily increased over the last number of years [9]. The Dublin Institute of Technology (DIT) is the largest third level institute in Ireland with in excess of 20,000 undergraduate students.

The standard route of entry to third level education in Ireland is through the Central Applications Office (CAO). Successful candidates gain entry to a chosen program once they reach the minimum points level set for that program in a particular year. Points are awarded, out of a maximum of 600 points, based on a student's performance in their six best subjects in a senior state examination known as the Leaving Certificate (LC) that takes place at the end of their final year in secondary school. Table I outlines the range of points that a student can obtain based on their performance in a particular exam. Mathematics exams can be taken at three levels: higher; ordinary; and foundation. Students who take mathematics at foundation level are not eligible for direct entry into third level. The minimum point's level for programs is determined by student demand and the limited number of places available.

TABLE I. LEAVING CERTIFICATE POINTS

Leaving Certificate Grade		Points Awarded		
		Higher Paper	*Ordinary Paper*	*Foundation Maths.*
A1	(90% - 100%)	100	60	20
A2	(85% - 89%)	90	50	15
B1	(80% - 84%)	85	45	10
B2	(75% - 79%)	80	40	5
B3	(70% - 74%)	75	35	---
C1	(65% - 69%)	70	30	---
C2	(60% - 64%)	65	25	---
C3	(55% - 59%)	60	20	---
D1	(50% - 54%)	55	15	---
D2	(45% - 49%)	50	10	---
D3	(40% - 44%)	45	5	---
E	(25% - 39%)	---	---	---
F	(10% - 24%)	---	---	---
NG	(0% - 9%)	---	---	---

B. National Framework of Qualifications

The National Qualifications Authority of Ireland (NQAI) is the agency charged with the responsibility of developing and promoting the implementation of a National Framework of Qualifications (NFQ) across education and training in Ireland. Fig. 1 illustrates the 10-level framework of the NFQ. Each level is based on specified standards of knowledge, skill and competence and ensures that qualifications are of a quality and standard recognized both nationally and internationally.

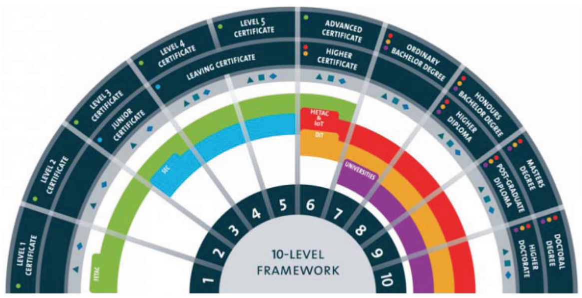

Fig. 1. The National Framework of Qualifications.

C. Awards Offered by Dublin Institute of Technology

The awards made by DIT are included in the NFQ from levels 6-10. In DIT entry to level 8 engineering programs (Bachelor of Engineering, BE) require the student to have a high mathematical ability with a minimum of a grade C (55%) in a higher level mathematics exam sought. Entry to most level 7 engineering programs (Bachelor of Engineering Technology, B. Eng. Tech.) requires a minimum of a grade D (40%) in a lower level mathematics exam. Students on Level 7 engineering programs tend to have a lower academic ability in mathematics which ultimately can lead to issues with confidence, motivation, engagement, and retention.

The route to both level 7 and level 8 engineering programs in DIT is illustrated in Fig. 2. Included in this figure is a general entry (non-denominated) route for students. This route is typically taken by students who either do not obtain the minimum grade in mathematics or do not achieve the required points for entry onto a selected level 8 program. It also provides students who may be unsure of which engineering discipline they want to study a path where they get a taste, through a diverse suite of modules, of the various engineering disciplines offered in DIT. Depending on end-of-year results, a student may gain entry to year 1 of a level 8 or year 2 of a level 7 engineering program.

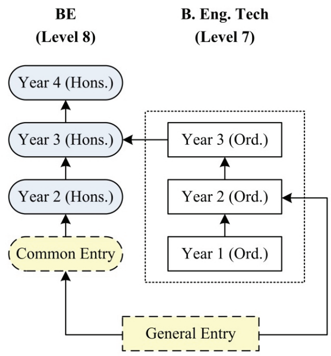

Fig. 2. Typical routes to level 7 and level 8 engineering programmes in DIT.

III. LITERATURE REVIEW

A. The Twenty-first Century Student

Bovill [10] describes a hierarchical approach to learning which places the '*expert tutor*' in front of '*subordinate learners*'. This predominately lecturer-focused approach is characterised by student passivity particularly among those who are less engaged in the learning process. A pedagogical shift is required to accommodate the differing needs and expectations of today's student with a rising interest among academics in engaging and empowering students as agents of their own learning [11]-[13].

This shift involves a move away from the traditional hierarchical model to one where students become '*agents in the process of transformative learning*' (Fielding, 1999; cited in [10]) with the learner becoming the main focus of the learning experience. Transformative learning allows the learner to develop cognitively, holistically and socially through active involvement in defined activities. The challenge now faced by educators is to explore and adapt to new pedagogical approaches. Duderstadt et al. [14] asserts that in these new learning models rather than being referred to as students these "*clients of the twenty-first century university*" should be referred to as "*active learners, since they will increasingly demand responsibility for their own learning experiences and outcomes.*"

The present cohort of students have grown up in a world which has been shaped and transformed by technology and are "*actively engaged with the IT-application-rich environment in which they find themselves*" [15]. The use of technology in its various forms means that those who have grown up and been immersed in it are more willing to adapt and thrive as technology advances and changes.

B. National Stratedgy for Higher Education

Within the European context, the need for a different approach to traditional teaching methods is supported by the

Bologna Declaration (1999) [16] which aims to reform the structures of higher education. From an Irish perspective the *National Strategy for Higher Education to 2030* [17] emphasizes the need of teachers in higher education to '*…simulate active, not passive learning, and to encourage students to be critical, creative thinkers, with capacity to go on learning after their college days are over.*'

C. Use of Technology to Enhance Student Learning

When the present cohort of third level students first entered the education system, many of the technologies available today did not exist while others were not readily available in the form that we now know them. From screencasts [18] to podcasts [19] to tablet PCs [20] the role of technology in higher education is increasing. The students' ability to quickly adapt and prosper in a world filled with technology offers new opportunities for the lecturer to exploit technology to facilitate and support new methods of learning.

Technology as a tool for enhancing the student learning experience is widely documented in research literature. However, almost all examples found document the use of technology by the lecturer to create course content. For example, Loch et al. [21] look at exploiting emerging technologies to complement mathematics support with online '*MathsCasts*'. The engagement of students in both cognitive and metacognitive processes using screencasts is explored by McLoughlin and Loch [22]. Kao [23] looks at using video podcasts to enhance students' learning experience in engineering. Pinder-Grover et al. [24] investigate using screencasts to enhance student learning in a large lecture material science and engineering course.

Graphic tablet technology as a teaching and learning tool is used in a number of disciplines from architecture to product design. As a teaching tool for mathematics, they are still not widely documented in research literature. However, one example [25] documents the use of graphic tablets by the lecturer to create course content. For this study, unlike [21]-[25], the student will create course content using graphic tablets.

D. Role of the Educator

The role of the educator to adapt to the changing nature of the engineering profession and student cohort is discussed by Lopez [26]. The diversity of today's student in terms of ability, learning styles, prior educational experiences and attainment requires a more comprehensive learning support system. From an Irish perspective a number of problems are now being faced by institutions offering engineering programs: lowering of entry requirements (CAO data) for many engineering programs; a decline in the mathematical ability of engineering students [6]; and the difficulty in teaching large classes with inadequate facilities caused by increasing numbers of students taking engineering programs [9]. To counter these and similar problems Broadbridge and Henderson [27] identified a number of methods which institutions and educationalists have begun to use such as problem/project based learning (PBL), online support, visual sources, online instructional materials, computer-aided assessment, flexible formative and summative assessment.

A variation of the PBL approach involves the inclusion of the student as co-creator of course content. This approach shifts the focus from content delivery by the lecturer to active engagement with content by the student. It has been shown that using this approach can achieve a greater sense of engagement [28] and by shifting the balance of power to the learner, an environment of achievement and ownership is created which empowers the student and increases self-efficacy.

E. The Role of Active Learning in Higher Education

The role played by active learning in higher education is discussed by Chickering and Gamson [29] who include it as one of their seven principles of good practice in undergraduate education. The potential role of technology was subsequently revisited with a view to exploring how technology could be used cost-effectively and appropriately to advance the seven principles [30]. Cromack [31] observes that where a "*symbiotic relationship exists between technology and learner-centered education*" an improvement in student learning is observed.

The primary aim of an active learning environment is to maintain and encourage students' motivation to learn, to inspire confidence and make them ambitious during their studies [32]. Rather than the student passively receiving information from the lecturer they are actively engaged in the activity and thus actively learning. According to Prince [33], "*active learning refers to activities that are introduced into the classroom. The core elements of activity are student activity and engagement in the learning process.*" This active learning constructivist approach also provides the student with an environment where they can identify their misconceptions and interact with resources including the lecturer to develop their understanding [27].

The empowerment of students when engaged in a deeper and more meaningful way through active learning is discussed by Armstrong et al. [34]. A number of ways in which this can occur are outlined by the author. These include developing capabilities to create multimedia presentations; developing a sense of professionalism; learning new social skills; enjoying a break from the routine; having a new and fun experience; and developing a stronger appreciation for planning and teamwork.

IV. Methodology

Based on the idea that teaching a concept is the best way to learn that concept, the students become active actors in the platform as they create the videos that will be used as feedback by other users of the platform. A '*learning with*', as opposed to a '*learning from*' approach to technology is employed. Student involvement in group projects which incorporate a hands-on component have been acknowledged as forming the basis of a successful pedagogical approach [35]. Reflection is encouraged as students prepare and view the results of their videos.

A. Participants in Study

The students who participated in this study are drawn from a first year level 7 general entry engineering program (DT097). A comparison of CAO entry points for DT097 with two other level 7 programs (DT004 - Civil Engineering; DT006 - Mechanical Engineering) as well as a first year level 8 common engineering program (DT097) is provided in Table II. The figure in brackets represents the mid-point entry CAO points. Based on CAO entry points students from the level 7 DT097 program compare quite favorably academically with those on the common level 8 program (DT025).

TABLE II. PROGRAMME ENTRY POINTS

Academic Year	Level 7			Level 8
	DT097	DT004	DT006	DT025
2010-11	---	220 (365)	230 (385)	340 (390)
2011-12	320 (430)	220 (360)	230 (365)	365 (430)
2012-13	360 (460)	240 (335)	300 (385)	350 (415)

Of the 37 students enrolled on DT097 only 7 (16%) took the higher level mathematics paper in the LC. Nationally, 25.6% took the higher level paper in 2012-13. The distribution of grades attained (see Table I) among those students who took the ordinary level mathematics paper is: A (i.e. 85% - 100%) = 2; B = 14; C = 4; and D = 10.

B. Approach Taken in Study

The approach employed for this study (see Fig. 3) follows the design-based approach described by Reeves et al. [36], the foundations of which lie in developmental research [37].

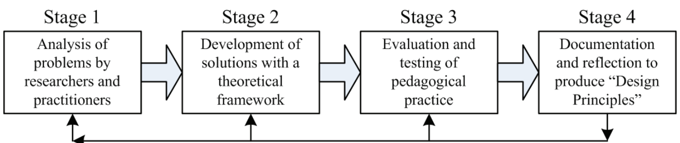

Fig. 3. Design based research stages.

It consists of an interactive cycle with an iterative sequence of analysis, design, evaluation and revision. A cycle of successive approximations continues until a balance between the initial ideals and the actual realization of the study are achieved. This approach is particularly beneficial to research aimed at '*exploring and exploiting the potential of information and communication technologies in education*' [36]. The four stages are broken down as follows:

- **Stage 1:** Core mathematical concepts which are proving difficult to understand are focused on. These may be initially identified using a standard MDT.
- **Stage 2:** A set of online quizzes is developed by the lecturer and includes feedback videos created by the student covering various topics. The students' disseminate knowledge on a mathematical concept.
- **Stage 3:** Evaluation of student performance through online quizzes. Students are encouraged to give feedback at regular intervals and demonstrate active performance.
- **Stage 4:** Outputs in the form of knowledge (student learning) and products (quizzes and videos). Feedback is obtained from students through surveys and focus groups. Usage data and scores from the online quizzes are analyzed.

The Learning Management System (LMS) used by DIT is webcourses (Blackboard). The online quizzes are created using Wondershare QuizCreator® [38] which can be integrated as a SCORM (Shareable Content Object Reference Model) quiz packages into webcourses. The principal function of the SCORM is to allow reusability and interoperability of learning resources across different LMS.

C. Student Created Solutions to Mathematical Problems

Solutions to mathematical problems are created by the student using graphic tablet technology (Wacom® Intuos Pen & Touch Medium [39]) and video creating software (HyperCam 2 [40]). They work collaboratively in groups of two/three to create a solution. Once a solution is obtained, a script for the video (see Fig. 4) is prepared and the graphic tablets are used to create the video with accompanying commentary (see Fig. 5). As part of the development of the solution the students' synthesize knowledge from various sources and engage with the concepts at a deeper level as they are required to explain the process, concepts and theory behind it.

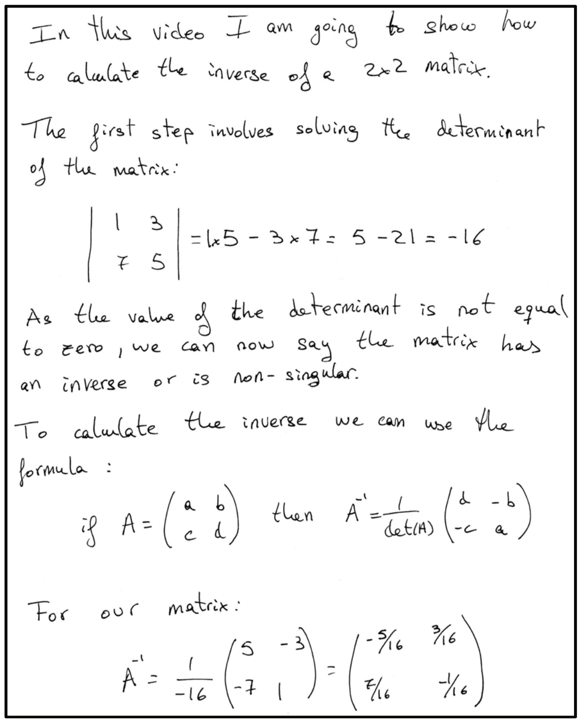

Fig. 4. Extract from a typical script written by the student.

Fig. 5. Students using a graphics tablet to record a video of a solution to a mathematical problem.

D. Creating the Online Quizzes Including Feedback Videos

The SCORM run-time environment (RTE) is illustrated in Fig. 6. Reusability and interoperability of learning resources across different LMS is achieved through a common means of '*launching*' learning resources. These resources communicate with the LMS through an Application Programming Interface (API) using a language such as JavaScript to implement RTE API function calls to the LMS.

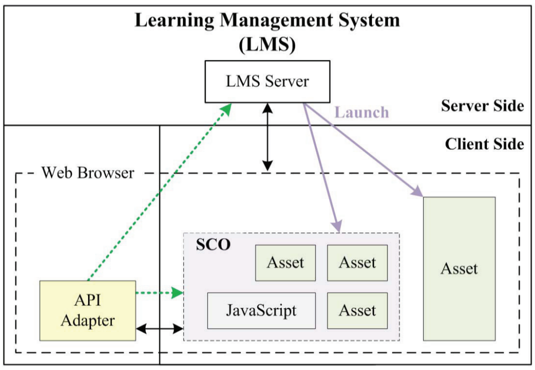

Fig. 6. The SCORM run time environment (adapted from [41]).

The SCORM objects (SCOs) are made up of quiz questions and feedback videos which are assembled into packages with delivery instructions. The LMS loads the SCOs and delivers them according to the instructions which detail the order and number of questions to be answered. This can be tailored to manage the different paths that can be taken depending on the answers provided by the student. Quiz questions are accessed in ascending order of difficulty as illustrated in Fig. 7.

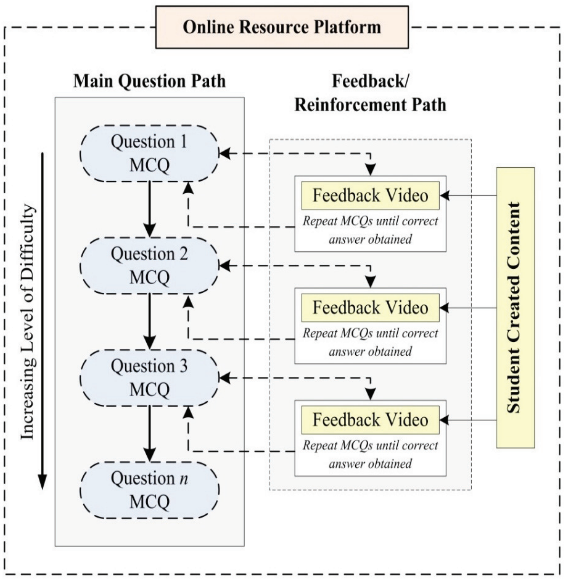

Fig. 7. Main question and feedback/reinforcement paths.

An incorrect answer will cause the student to be re-directed from the main question path (MQP) to the feedback/reinforcement path (FRP). From here the student may view videos created by their peers to help reinforce the concept being examined by the quiz question. On successful completion of a question the student is re-directed back to the MQP where they can proceed to the next question. A typical question from the MQP and its associated feedback path are illustrated in Fig. 8 and Fig. 9 respectively.

Question (Main Question Path): **Which of the following matrices is singular?** $A = \begin{pmatrix} 1 & 8 \\ 2 & 16 \end{pmatrix}$ $B = \begin{pmatrix} 3 & 8 \\ 2 & 6 \end{pmatrix}$	
Possible solutions	**(a)** A is singular because its inverse doesn't exist. **(b)** B is singular because its inverse exits. **(c)** Both A and B are singular because their values are not equal to zero. **(d)** None of the two matrices are singular.

Fig. 8. Sample quiz question from MQP.

Question (Feedback/Reinforcement Path): **Find the inverse of** $A = \begin{pmatrix} 5 & 2 \\ 2 & 6 \end{pmatrix}$	
Possible solutions	**(a)** A has no inverse **(b)** $A^{-1} = \begin{pmatrix} 6 & 2 \\ 2 & 5 \end{pmatrix}$ **(c)** $A^{-1} = \begin{pmatrix} 6 & -2 \\ -2 & 5 \end{pmatrix}$ **(d)** $A^{-1} = \begin{pmatrix} 6/26 & -2/26 \\ -2/26 & 5/26 \end{pmatrix}$

Fig. 9. Sample quiz question from FRP.

V. Results

A. Maths Diagnostic Test

The mathematical capabilities of the students were initially measured using a standard MDT [6]. A breakdown of the results is illustrated in Fig. 10. The MDT was chosen over LC mathematics results as it allows all non-standard applicants who may have taken an alternative route into the program as well standard CAO applicants to be included. The results from the MDT show a greater proportion of grades in the lower half (<50%) of the range suggesting a poor understanding of core mathematical concepts.

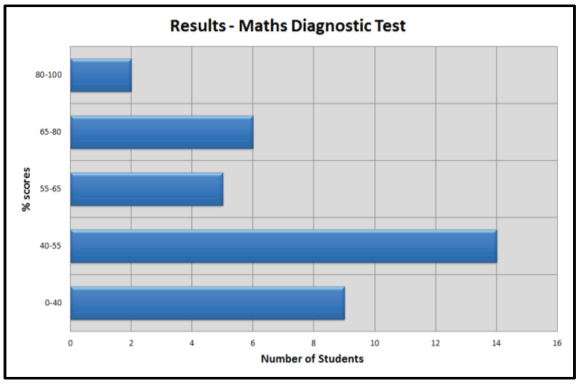

Fig. 10. Results from the maths diagnostic test.

Following the MDT, two sub-groups were identified based on performance i.e. students with a score ≥50% and students with scores <50%.

B. *Student Survey*

A survey was conducted amongst those students who participated with responses based on a five-point Likert scale (*1-Strongly Disagree, 2-Disagree, 3-Neither Agree/Disagree, 4-Agree, 5-Strongly Agree*). Average responses are listed in Table III (n = 21). The responses received from the survey are illustrated in Figs. 11 to 15.

TABLE III. STUDENT SURVEY

Statement	Average Response
Creating the videos was a very useful tool for learning.	3.90
Recording the videos allowed me to practice what I learned in the lecture and reinforce the core concepts outlined.	4.24
I am planning to use all the on-line resources (quizzes and videos) for revision in preparation for my module exam.	3.74
I would recommend creating videos for other subjects.	3.86
If you could rewrite the maths module, you would remove the video component.	1.90

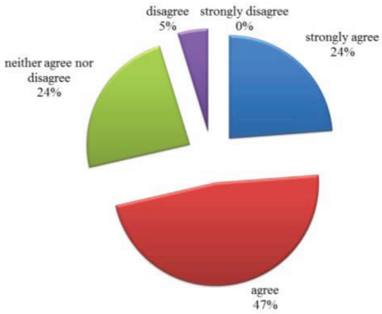

Fig. 11. Statement: '*Creating the videos was a very useful tool for learning.*'

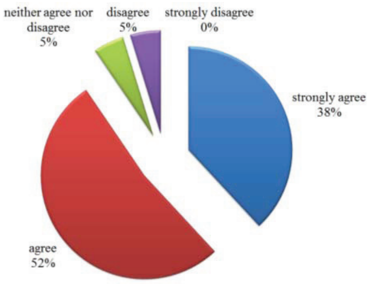

Fig. 12. Statement: '*Recording the videos allowed me to practice what I learned in the lecture and reinforce the core concepts outlined.*'

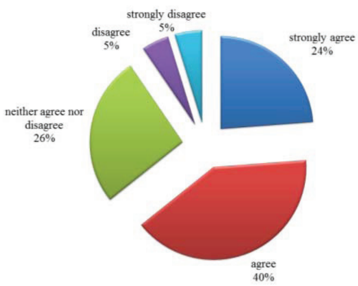

Fig. 13. Statement: '*I am planning to use all the on-line resources (quizzes and videos) for revision in preparation for my module exam.*'

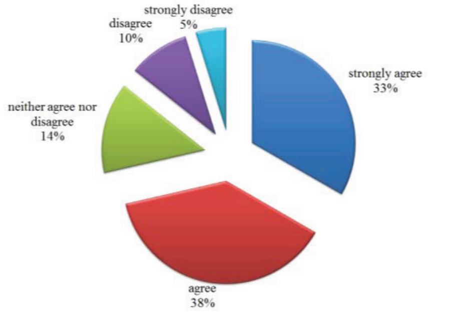

Fig. 14. Statement: '*I would recommend creating videos for other subjects.*'

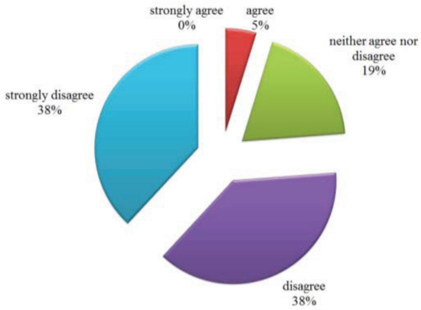

Fig. 15. Statement: '*If you could rewrite the maths module, you would remove the video component.*'

A question was also posed about student preference for the amount of time spent on tutorial sessions where videos were created, as part of an active learning setting, to those which took the form of a traditional tutorial session. Fig. 16 shows the responses broken down into two categories i.e. those who obtained ≥50% in the MDT and those who achieved <50%.

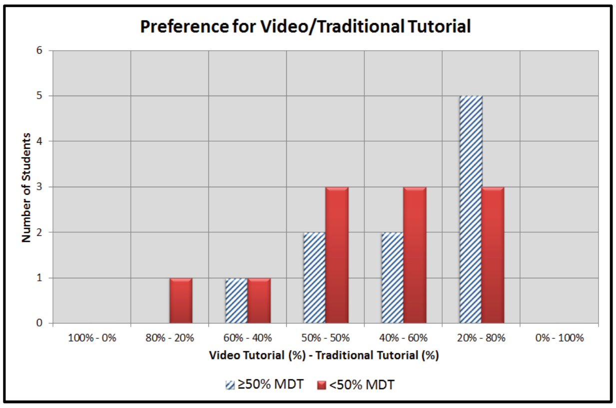

Fig. 16. Student preference for video / traditional tutorials.

The students' responses show a general preference for a mix of traditional and video tutorial sessions. A point to note is that no student showed a preference for a 100% session using one or the other method.

When the results are divided into the responses of the two sub-groups, the lower scores sub-group tends to prefer higher percentage of tutorials creating videos than the sub-group with higher scores. This result is also evident where the students were asked if they would re-write the module to eliminate the video tutorial sessions and replace them with traditional tutorials. The students with a MDT score <50% either disagree or strongly disagree to eliminating the video tutorials are 80%, with 20% neither agreeing nor disagreeing. Comparison between Fig. 15 and Fig. 17 confirms the trend evidenced in Fig. 16 in so much that students with lower MDT scores (<50%) prefer the module to include the creation of videos.

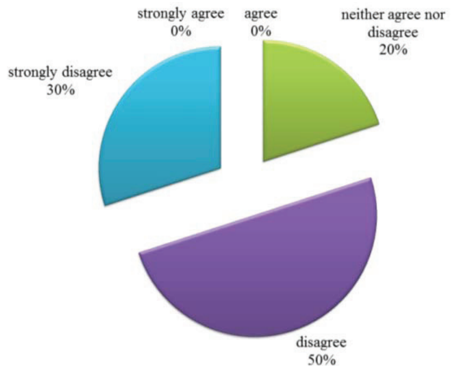

Fig. 17. Statement: '*If you could rewrite the maths module, you would remove the video component.*'

VI. Discussion/Conclusions

This study stems from a pilot study carried out by Llorens [42] into the use of online video for mathematics peer instruction. Results from that study showed that the active learner approach to online videos, where the students solve a problem and disseminate that solution to their peers via online videos, increases student engagement, encourages deeper thought, increases motivation and provides confidence for weaker students.

For this paper the pedagogical potential of using graphic tablet technology as an effective teaching and learning tool in an active learning constructivist environment was explored. The online platform which consists of the student created videos and the quizzes is intended to reinforce core concepts and provide students with a multimedia tool created mainly by students for the benefit of other students. As well as strengthening their core competencies in mathematics, they have developed a set of transferrable skills that will benefit them beyond the confines of their studies: teamwork; communication; planning; and technical literacy.

The general perception amongst the students was that the videos were a useful and enjoyable way of learning. However, the preferred method for tutorial sessions was a mix between traditional sessions and video sessions. Of the students surveyed no one preferred 100% traditional or 100% video sessions. The results show a preference amongst weaker students (MDT scores) for non-traditional tutorials and online content. This preference is expressed by students who created and viewed the videos.

In this paper, we have presented the development and evaluation of student perceptions of an online resource platform consisting of students' videos and quizzes. The results obtained show that students engage actively with technology. Their experience is enriched by the active learning environment and this is reflected in their perceptions and attitudes towards the discipline. This active learning and constructivist approach will provide an environment of achievement and ownership that will empower students of all levels to benefit from the learning experience.

VII. Future Work

This project represents the first stage of a longitudinal study which will work toward expanding the bank of quiz questions and feedback videos. Students will be tracked as they progress through subsequent stages of the program to see if their performance improves as a result of creating the videos or from simply viewing the online resources. The platform will grow as new and improved resources are added. Extending the platform to cover other technical subjects such as physics or chemistry will also be explored.

Acknowledgments

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