Constructionism and microworlds as part of a 21st century learning activity to impact student engagement and confidence in physics

Conor M Wickham, *cwickham@tcd.ie*
The Trinity Centre for Research in IT in Education, School of Computer Science & Statistics and School of Education, Trinity College Dublin, the University of Dublin, Dublin 2, Ireland

Carina Girvan, *girvanc@cardiff.ac.uk*
School of Social Sciences ¦ Cardiff University
Glamorgan Building ¦ King Edward VII Avenue ¦ Cardiff ¦ CF10 3WT, UK

Brendan Tangney, *tangney@tcd.ie*
The Trinity Centre for Research in IT in Education, School of Computer Science & Statistics and School of Education, Trinity College Dublin, the University of Dublin, Dublin 2, Ireland

Abstract

The affordances of microworld simulations to promote student engagement and motivation are well documented in the literature. These technologies which can be highly have the potential to enhance a student's learning experience. Nevertheless their widespread use in mainstream secondary school classrooms remains limited as these technologies do not sit well in conventional classroom settings, where short class durations, didactic pedagogy and an emphasis on teaching to the test prevail.

The problems in secondary school STEM education, such as declining number of students considering a career in science related disciplines, have often been linked to didactic teaching styles in classrooms, with an emphasis on transference of knowledge from the teacher to student and where text books are the main source of curriculum content. In physics, teaching is often focused on the application of mathematical formulae and lacks context and applicability to real world problems. As a result many students find physics a 'difficult and hard subject to study' leading to poor motivation and low engagement with the subject. This research brings three key elements together - microworld technology, a constructionist, contextualised pedagogy and a 21st century learning model – to investigate their combined impact on student engagement and confidence in physics. Students worked in teams using a constructionist microworld simulation to build electrical circuits. An exploratory case study was carried out involving 39 secondary school students (aged ~15/16) participating in 4 separate physics workshops.

An attitudinal questionnaire was used for quantitative data capture, while focus groups and observation provided rich qualitative data for triangulation. The findings from the study indicate positive changes in student engagement, confidence in physics and attitude to the use of technology for learning. The qualitative data provides context for these findings, which while being based on a modest sample in terms of the number of participants and duration of the learning experience, nevertheless support the hypothesis that a 21st century pedagogical approach is a suitable framework for exploiting the potential of microworlds to promote engagement and confidence in physics.

Keywords

Constructionism, Social Constructivism, Microworlds, 21st Century Learning, Bridge21, Engagement, STEM, Contextualised Learning.

1: Introduction

> '***Microworld***: *An interactive, exploratory learning environment of a small subset of a domain that is immediately understandable by a user and also intrinsically motivating to the user. A microworld can be changed and modified by the user in order to explore the domain and to test hypotheses about the domain.'* Rieber (2005)

Microworlds have been likened to playpens or sandboxes, providing the learner an opportunity for creative exploration and there is extensive literature highlighting the potential of simulations and microworlds to support student engagement and conceptual understanding. Simulations usually provide a representation of physical phenomena, with varying levels of interactivity which allow the user modify, create or alter parameters that will generate a response within the simulation. Several research studies have examined the affordances of simulations to develop deeper conceptual understanding (Girvan, 2014; Martínez, Naranjo, Pérez, Suero, & Pardo, 2011; Perkins, Moore, Podolefsky, Lancaster, & Denison, 2012; Zacharia & de Jong, 2014). In particular the ability of simulations to benefit a learners understanding through visualisation has been demonstrated in science subjects (Blikstein, Fuhrmann, Greene, & Salehi, 2012; Chiu, DeJaegher, & Chao, 2015). While research into constructionist virtual worlds to support creative mathematical thinking points to the importance of collaboration and sharing of created artefacts (Kynigos, Moustaki, Smyrnaiou, & Xenos).

The problems in secondary school STEM education, such as declining number of students considering a career in science related disciplines, have often been linked to didactic teaching styles in classrooms, with an emphasis on transference of knowledge from the teacher to student and where text books are the main source of curriculum content. In physics, teaching is often focused on the application of mathematical formulae and lacks context and applicability to real world problems. As a result many students find physics a 'difficult and hard subject to study' leading to poor motivation and low engagement with the subject. The use of technology in general and micorworlds in particular have the potential to help address at least some of these barriers. However traditional classroom environments, with didactic teaching style and short class durations are not ideal environments in which to exploit the power of learning through technology (McGarr, 2009). Instead the constructivist and constructionist pedagogies at the core of models for 21st century learning (Dede, 2010) may be much more suitable frameworks to capitalise on the power of technology in general and micro-worlds in particular (B. Tangney, Bray, A., & Oldham, E., 2015).

21st Century Learning Environment

Bridge21, a specific model of 21st century learning, has been shown to be an effective environment for technology mediated learning (Bray, Oldham, & Tangney, 2013; Conneely, Girvan, Lawlor, & Tangney, 2015; Johnston, Conneely, Murchan, & Tangney, 2014; B. Tangney & Bray, 2013). In particular in the area of mathematics Tangney et al (B. Tangney, Bray, A., & Oldham, E., 2015) have investigated the combination of mobile technology with contextual and social constructive pedagogies such as Bridge21. The initial results of this 'perfect storm' (as referred to by the authors) are very positive and 'student engagement and appreciation of mathematics content are favourably affected'.

This research study follows a similar approach, but in this case the subject area is physics and investigates the combination of microworld technology, a constructionist, contextualised pedagogy and the Bridge21 learning model. Physics is chosen as the subject domain because of the decline in the number of secondary level students studying physics, which research from several countries (Lyons, 2006) attributes to transmissive teaching styles and a perceived lack of relevance. Even with students who do study the subject research points to low levels of engagement and poor conceptual understanding of the core concepts in physics (Azevedo, 2006; Saleh, 2011).

Research Questions and Goals

The research was undertaken as part of a larger project, looking at the introduction of 21st Century Teaching & Learning in Irish secondary schools (age 12-16), and sought to investigate how microworlds, when used as part of a 21st century learning model, impact student engagement and confidence in physics?

2: Design & Methodology

Overview of the Learning Activity

The microworld selected for use in the study was from the Physics Education and Technology (PhET) project at the University of Colorado[1] and it was chosen because it allows for a high degree of interactivity, has strong construction capabilities and is highly immersive. The Circuit Construction kit is a low floor, medium ceiling, microworld, easy for students to engage with but sufficiently challenging for more advanced users. It is constructionist in its pedagogical approach, allowing for concrete and abstract representations and supports cognitive conflict and investigation of alternate models.

The Circuit Construction Kit microworld was incorporated into a 5 hour Bridge21 workshop at the researcher's institution. 3 separate workshops with ~10 students in each were run and formed the basis of this research sample. This together with an initial pilot workshop consisting of 8 participants gave a total sample size of n=39 students over 4 workshops. The workshops incorporated real world, problem based activities that required participants to construct both series and parallel electrical circuit designs for set of Christmas tree lights and explain their choice and potential design benefits.

The Mathematics and Technology Attitudes Scale (MTAS) developed by (Pierce, Stacey, & Barkatsas, 2007) measures 5 variables related to the learning of mathematics with technology: Mathematics Confidence (MC), Confidence with Technology (TC), Affective Engagement (AE), Behavioural Engagement (BE), and attitude to learning mathematics with technology (MT). The questionnaire was modified for use in this study and was administered pre and post the workshops.

3: Implementation

The 39 students, of mixed gender, came from five different schools. Many of the participants had attended Bridge21 workshops in the past and thus were already familiar with the structure and team collaboration elements. This helped ensure that the investigation could focus on the use of microworlds and was not overly influenced by the novelty of the Bridge21 experience itself.

Data Collection & Analysis

Quantitative data was collected using the modified MTAS questionnaire while qualitative data was gathered through pre and post questionnaires, focus groups, observation and student output during the workshop activities. Qualitative and quantitative data was collected at the same time, both were analysed separately allowing for an element of triangulation to provide deeper insight into the research questions. See Figure 4.

Focus group interviews were run immediately after each workshop and each group comprised of between 4 and 6 participants and the discussion was recorded (using an unobtrusive smartphone recording app). 8 separate focus group discussions were recorded which yielded well over an hour of data to be analysed.

[1] https://phet.colorado.edu/

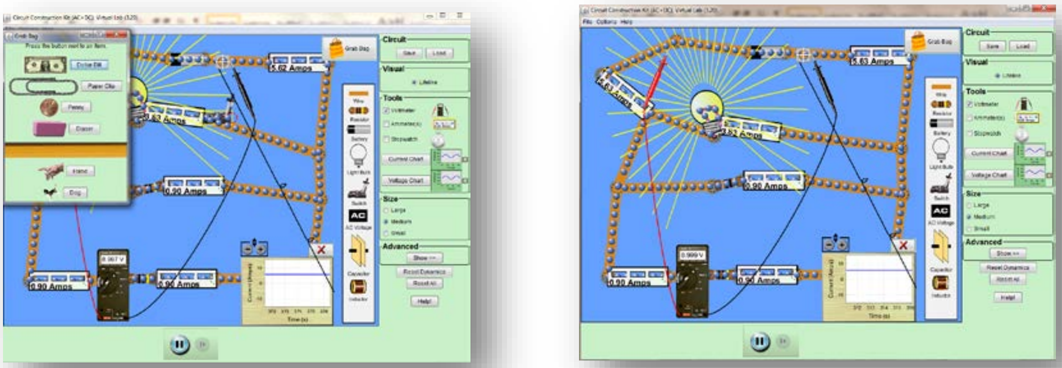

Figure 2: PhET Circuit Construction Kit illustrating complex circuit design. The user has access to accurate measuring tools such as ammeters, voltmeters and results are immediate.

Figure 3: The Bridge21 learning space. Workstations are fully configurable and can be easily rearranged to suit specific needs. Large monitors support sharing within the team.

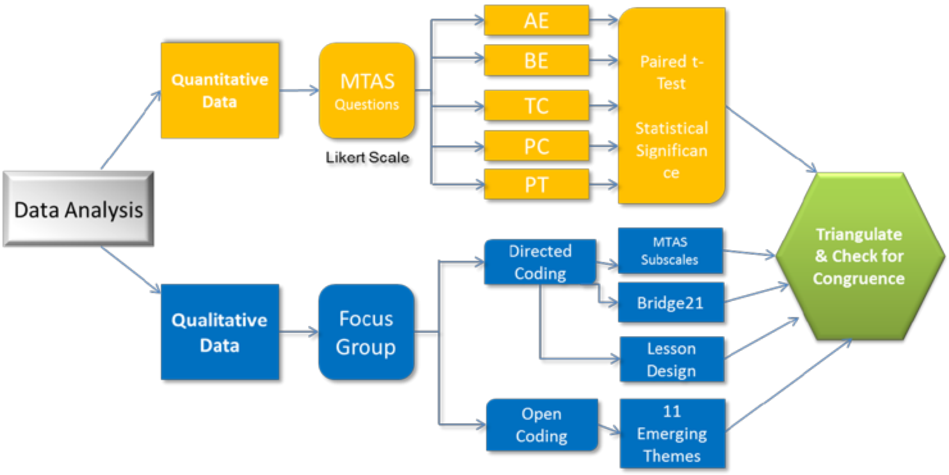

Figure 4: The data analysis framework used in this parallel mixed method case study. Congruence between quantitative and qualitative data supported the research findings.

4: Findings

MTAS Survey – Statistical Analysis

Examining the t values in Table 1 shows that 4 of the 5 MTAS subcategories show significant positive differences after the workshop namely: **Affective Engagement (AE)**, **Behavioural Engagement (BE)**, **Physics Confidence (PC)** and **Attitude to the use of technology in teaching physics (PT)**. For PT (t=6.894) the change was very significant indicating that the participants had a positive reaction to the PhET Circuit Construction Kit microworld. Only Technology Confidence (TC) with t= 1.275 showed no significant change pre and post workshop activity.

		Paired Differences						
					95% Confidence Interval of the Difference			
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	Sig. (2-tailed)
Pair 1	BE Post - BE Pre	.68421	1.67824	.27225	.13259	1.23584	2.513	.016
Pair 2	TC Post - TC Pre	.42105	2.03525	.33016	-.24792	1.09002	1.275	.210
Pair 3	AE Post - AE Pre	1.23684	2.18637	.35468	.51820	1.95549	3.487	.001
Pair 4	PC Post - PC Pre	1.18421	2.16677	.35150	.47201	1.89641	3.369	.002
Pair 5	PT Post - PT Pre	3.92105	3.50584	.56872	2.76871	5.07339	6.894	.000

Table 1: Results of the paired t-test analysis on the pre and post workshop MTAS questionnaires. At 95% confidence interval a t value greater than 2.021 is significant.

Qualitative Data

Both Open and Directed coding techniques were used to analyse the data and the results of directed coding of the focus group data against the MTAS subscales aligns well with the quantitative data. The frequency of occurrence of the open coding themes was highest for a positive reaction to the physics workshop for PT, PC, AE and BE, again in that order. This matches the order of the measured impact from the MTAS data.

Engagement Impact

The research identified several factors that contributed to the increase in behavioural (BE) and affective engagement (AE). These are: Microworld Technology; Collaboration; Self-Discovery.

The constructionist capability of the PhET microworld was a significant factor in the improvement of participants' affective engagement. The PhET microworld allowed students to create their own models and use these to confirm or challenge their understanding of the underlying concepts. The microworld also enabled students to see and understand abstract concepts such as electron flow, capacitor charging, neither of which cannot be easily grasped through textbooks or real physical experimentation.

Collaboration played an important part during the workshops in promoting engagement. Students worked in teams, discussed their solutions and were asked to present back to the whole group and this aspect was seen as positive by the participants.

> *'I think like, when you found the problem and you solved it and the light came on and it worked, and you got passed the problem as a team and you had a working circuit then, I think that was the best bit.'*

Impact on Confidence in Physics

The research findings offer statistical evidence that these workshops made a significant improvement in the students' attitudes to physics and to their confidence with the subject and two main factors contributing to this emerge from a structured analysis of the qualitative data, namely the Bridge21 workshop format (when contrasted with their conventional class experience) and the contextualised nature of the learning.

The contrast between the Bridge21 model with the participants own class experience was very evident from the workshop focus groups as typified by statements such as

> *'Because it wasn't like school. It was like, I don't know—because you didn't tell us we have to do this, and then this and then this. We got to just learn how to do it ourselves, kind of. And it makes you understand it more and it is more fun than just being told what to do.'*

> *'Like with that Ohm thing, I learned that in five minutes. But in school I couldn't even remember it from the book. Because it showed you exactly what was going on with the computer.'*

By contextualising the learning of physics to real life situations during the Bridge21 workshops students had a basis from which to understand the concepts and then apply the underlying mathematics to solve the problem.

> *'Because you know which way the circuits were actually moving. Like you know which way it is all set up. Instead of just looking at picture of piece of wires on the ground. You actually look at the simulation and see how it all fits together.'*

> *'Yeah, I just viewed it as a school subject. But after the workshop you see it is a lot more real-world stuff. '*

Technology Effectiveness

With a t value =6.894, student attitudes to using technology in physics learning (PT) showed the most statistically significant change as a result of the workshops. The choice of microworld technology was a major factor in this improvement. The data suggests several features of the PhET microworld that led to this positive change; visualisation; experimentation and construction capabilities. The microworld allowed students to "do physics" and imagine and create new models in ways that is not possible with existing teaching methods.

> *'I didn't know that electricity was the flow of electrons. You could see the way that they were going around. So that was good.'*

> *'I think if because you could see it and you didn't have to imagine it like you normally did in class and stuff. And then you could move them around and make stuff so it helped.'*

A recurring theme during the focus groups related to the constructionist features of the microworld and participants being able to 'do things'. With the freedom to create, students developed their own models and views of the circuits they constructed. Since the PhET software is based on real electrical principles students often created circuits that did not work or because of voltage irregularities gave unexpected outcomes. This challenged students to understand what was happening and propose a solution.

> *'And doing things in a more interactive, and like hands on way…. start learning things a lot easier when they do it hands on.'*

> *'Because we were actually able to see how a circuit gets put together. And we done a lot of experimentation as well. You know and, I suppose you can be told how something works but unless you, kind of, try it yourself and try different ways of doing things you don't really learn much.'*

Summary

The authors are engaged in a large scale design based research project which is working with teachers and schools across Ireland to embed 21st Century Teaching and Learning practices in mainstream secondary schools (Conneely et al., 2015; Johnston et al., 2014). A core premise of that work is that a 21st century learning model, such as Bridge21, is a more suitable framework for exploiting the potential of technology to support constructivist and constructionist learning than the traditional didactic model. This study looks at student engagement and confidence in physics when following such an approach. Carried out in an out of school setting the data indicates that both engagement with, and confidence in, physics improved as a result of the learning experience. The data also suggests that the attitude towards using technology in the study of physics improved. Factors which contributed to these improvements include the constructionist nature of the simulation, collaboration between peers and the contextualised nature of the learning activity.

The limitations of the study are its short duration, the lack of longitudinal follow-up with the participants to see if the intervention had any lasting impact and the fact that the activity took place in an out of school setting. Nevertheless this study, combined with our other experience of transitioning learning activities from our learning space to schools, gives confidence that the approach followed is transferrable to a real classroom setting and ongoing research will investigate this in practice.

References

Azevedo, F. S. (2006). Personal Excursions: Investigating the Dynamics of Student Engagement. *International Journal of Computers for Mathematical Learning, 11*(1), 57-98.

Blikstein, P., Fuhrmann, T., Greene, D., & Salehi, S. (2012). *Bifocal modeling: mixing real and virtual labs for advanced science learning.* Paper presented at the Proceedings of the 11th International Conference on Interaction Design and Children.

Bray, A., Oldham, E., & Tangney, B. (2013). *THE HUMAN CATAPULT AND OTHER STORIES– ADVENTURES WITH TECHNOLOGY IN MATHEMATICS EDUCATION.* Paper presented at the 11th International Conference on Technology in Mathematics Teaching (ICTMT11).

Chiu, J. L., DeJaegher, C. J., & Chao, J. (2015). The effects of augmented virtual science laboratories on middle school students' understanding of gas properties. *Computers & Education, 85*(0), 59-73. doi:http://dx.doi.org/10.1016/j.compedu.2015.02.007

Conneely, C., Girvan, C., Lawlor, J., & Tangney, B. (2015). An Exploratory Case Study into the Adaption of the Bridge21 Model for 21st Century Learning in Irish Classrooms, in Shaping our Future: How the lessons of the past can shape educational transformation. *Butler D., Marshall K., and Leahy M., Editors, Liffey Press: Dublin.*, p. 348-341.

Dede, C. (2010). Comparing frameworks for 21st century skills. *21st century skills: Rethinking how students learn*, 51-76.

Girvan, C. (2014). Constructionism, Creativity and Virtual Worlds. *Constructionism and Creativity: Proceedings of the 3rd International Constructionism Conference 2014. Vienna, Austria: Austrian Computer Society.*, p367-377.

Johnston, K., Conneely, C., Murchan, D., & Tangney, B. (2014). Enacting key skills-based curricula in secondary education: lessons from a technology-mediated, group-based learning initiative. *Technology, Pedagogy and Education*(ahead-of-print), 1-20.

Kynigos, C., Moustaki, F., Smyrnaiou, R., & Xenos, M. HALF-BAKED MICROWORLDS AS EXPRESSIVE MEDIA FOR FOSTERING CREATIVE MATHEMATICAL THINKING. *Constructionism and Creativity: Proceedings of the 3rd International Constructionism Conference 2014. Vienna, Austria: Austrian Computer Society.*

Lyons, T. (2006). Different Countries, Same Science Classes: Students' Experiences of School Science in Their Own Words. *International Journal of Science Education, 28*(6), 591-613.

Martínez, G., Naranjo, F. L., Pérez, Á. L., Suero, M. I., & Pardo, P. J. (2011). Comparative study of the effectiveness of three learning environments: Hyper-realistic virtual simulations, traditional schematic simulations and traditional laboratory. *Physical Review Special Topics - Physics Education Research, 7*(2), 020111.

McGarr, O. (2009). The development of ICT across the curriculum in Irish schools: A historical perspective. *British Journal of Educational Technology, 40*(6), 1094-1108. doi:10.1111/j.1467-8535.2008.00903.x

Perkins, K., Moore, E., Podolefsky, N., Lancaster, K., & Denison, C. (2012). Towards research-based strategies for using PhET simulations in middle school physical science classes. *AIP Conference Proceedings, 1413*(1), 295-298. doi:10.1063/1.3680053

Pierce, R., Stacey, K., & Barkatsas, A. (2007). A scale for monitoring students' attitudes to learning mathematics with technology. *Computers & Education, 48*(2), 285-300. doi:http://dx.doi.org/10.1016/j.compedu.2005.01.006

Rieber, L. P. (2005). Multimedia learning in games, simulations, and microworlds. *The Cambridge handbook of multimedia learning*, 549-567.

Saleh, S. (2011). The Level of B.Sc.Ed Students' Conceptual Understanding of Newtonian Physics. *International Journal of Academic Research in Business & Social Sciences, 1*(3), 249-256.

Tangney, B., & Bray, A. (2013). Mobile Technology, Maths Education & 21C Learning. *QScience Proceedings*(12th World Conference on Mobile and Contextual Learning [mLearn 2013).

Tangney, B., Bray, A., & Oldham, E. (2015). Realistic Mathematics Education, Mobile Technology & The Bridge21 Model For 21st Century Learning – A Perfect Storm. In H. T. J. Crompton (Ed.), *Mobile Learning and Mathematics: Foundations, Design and Case Studies* (pp. 96-105): Routledge.

Zacharia, Z. C., & de Jong, T. (2014). The Effects on Students' Conceptual Understanding of Electric Circuits of Introducing Virtual Manipulatives within a Physical Manipulatives-Oriented Curriculum. *Cognition and Instruction, 32*(2), 101-158.