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An inquiry-based learning intervention to support post-primary engagement with science, technology, engineering and mathematics

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Abstract
Science and mathematics education in Ireland is facing an increasing number of challenges due to economic and social change. Some of these challenges mirror international trends while others are unique to the Irish education system. In order to meet the demands that are being placed on science and mathematics education in Ireland at post-primary level, the time might be right for the implementation and support of university-based interventions. This paper describes an inquiry-based learning intervention for post-primary students that seek to sustain and nurture student interest in science, technology, engineering and mathematics. The intervention is an example of how institutions of higher education can support post-primary students by giving them the confidence needed to face the challenges of a 21st century society.

Keywords: Inquiry-based learning, STEM education.

Global Trends in STEM Education

Education in a 21st century society bears the responsibility for preparing young people to realise their potential amidst rapid social and economic change. Schools are tasked with having to "prepare students for jobs that have not yet been created, technologies that have not yet been invented and problems that we don't yet know will arise" (Schleicher, 2011, p.42). While this is a noble sentiment there are a number of obvious challenges when trying to meet objectives that are shrouded in uncertainty. Globally, the focus of meeting these objectives has led to the promotion of 'STEM Education, where the STEM acronym stands for Science, Technology, Engineering and Mathematics. The evolution of the STEM acronym can be traced back to the 1990s when the National Science Foundation in the United States invested heavily in science, mathematics, engineering and technology (SMET), stating that the "quality of our future technological achievements depends heavily on the education in science, mathematics, engineering and technology (SMET)" (National Science Foundation, 1998). 'SMET', as an acronym, failed to catch on and was replaced with STEM by Judith A. Ramaley during her time as the assistant director for education and human resources at the National Science Foundation from 2001 to 2004 (Rimes & de la Barra, 2014). STEM became a more widely-known acronym thanks to the popularity of books like "The World is Flat" (Freidman, 2005) which highlighted how traditional emerging economies like India and China were catching up on the US economy, and could potentially surpass it, due to their investment in STEM education. As a result, the US government invested heavily and the STEM acronym quickly became ubiquitous with western education (Sanders, 2008).

The availability of funding for STEM initiatives in the European Union also saw the acronym proliferate among European countries. Horizon 2020 is the research and innovation funding programme of the European Commission and has posed a series of 'Societal Challenges' that will rely on STEM research over the next seven years to help tackle the economic and social challenges facing European society (European Commission, 2013). These challenges range from topics such as health, food, energy, transport, climate, equality and freedom and will receive almost €30 billion in funding — more than 35% of the entire budget for Horizon 2020. This funding is expected to be utilised by researchers in STEM education, particularly in higher education, as noted by Cortese (2003): "If higher education does not lead the sustainability effort in society, who will?". Despite the availability of funding, implementing a coherent approach to supporting STEM education has proven difficult. Attempts to incorporate each of the core subjects into a consistent curriculum have been met with constraints and challenges which has seen the STEM acronym struggle to cement itself in the educational environment. Failures to consider STEM as a true curriculum concept and an overemphasis on science and mathematics to the detriment of technology and engineering are among the chief concerns (Herschbach, 2011).

It is debatable whether STEM, as an acronym, is fit-for-purpose in 21st century education. It is facing questions from a growing number of researchers that feel it should be replaced by STEAM, with the additional 'A' representing the arts which many feel are integral to providing the creativity needed for innovation (Connor *et al*., 2015). The situation is further complicated by calls for additional letters in the acronym to create STREAM — with the 'R', confusingly, standing for everything from 'reading', 'wRiting', 'research' and even 'robotics' (Ostler, 2012; Stubbs & Yanco, 2009). As with STEM, additional acronyms could cause curriculum design to be constrained by efforts to cater specifically to the subjects represented by the letters in the acronyms. At this point it could be argued that the term 'science' might be more inclusive than any combination of acronyms as its history and relevance to other fields mean that as a broad term it can often incorporate elements of technology, engineering and mathematics. In this paper, however, the STEM acronym will be used as the selected term to refer to educational expectations in 21st century society.

STEM Education in Ireland

The prevalence of the STEM acronym within the Irish education system has gradually risen to the same level of ubiquity as has been seen in the US. A STEM education in 21st century Ireland comes with its own complications due to the additional responsibility placed on the Irish post-primary education system to prepare young people to succeed in a 'knowledge-based economy' still reeling from the global financial crisis and subsequent recession (Quinn, 2012).

Of the four STEM subjects, each faces its own unique challenges in post-primary education in Ireland. In junior cycle post-primary education (generally 12 - 15 year old students), science is not a compulsory subject. It has been more than a decade since the curriculum for junior cycle science has been updated, and although there have a number of reforms proposed in recent years they have become mired in controversy. In 2012, the then Irish Minister of Education Ruairi Quinn proposed a new curriculum and assessment framework which was met with unequivocal opposition from the teacher unions and became subject to widespread national media coverage (Erduran & Dagher, 2014). In senior cycle post-primary education (16 - 18 year olds) the number of young people choosing to take the physical science subjects has been in decline since the 1990s (Smyth & Hannan, 2006).

Technology and engineering face arguably greater challenges in post-primary Irish schools. Engineering is offered as a practical subject to senior cycle students but has low uptake, while technology has been suffering for decades due to delayed state policies on computers in education. Although the use of information and communications technology (ICT) in Irish post-primary schools received a major stimulus in 1997 with the launch of the Government's Schools IT 2000 initiative (Conway, 2000), which resulted in €50 million of state funds being invested in post-primary school ICT infrastructure and training over the following three years, interest quickly waned due to a lack of ongoing investment in ICT resources and continuing professional development (McGarr & Kearney, 2009). It took almost two decades for the subsequent 'Digital Strategy for Schools: 2015-2020' to be launched (Butler *et al.*, 2015). Despite longstanding calls to have computer science and programming introduced into Irish schools, they remain largely absent from schools in any formal capacity (McGarr, 2009).

The subject area that has made the most progress towards supporting students in 21st century society is mathematics. 'Project Maths' is a major education initiative that involved revised syllabuses at both junior and senior cycle level in post-primary education in Ireland (Prendergast & O'Donoghue, 2014). Its introduction was seen as crucial to addressing the poor uptake of mathematics — "Of particular concern is the persistently low number of upper second-level students taking higher-level mathematics, which undermines the preparedness of students for engagement with engineering and the physical sciences" (Hunt, 2011, p. 36). While the introduction of Project Maths had the objective of making mathematics more skills-focused and more applicable to everyday life, initial results suggest that students taking the new syllabuses in post-primary education are still facing difficulty engaging with mathematics as a university-level subject (Treacy & Faulkner, 2015; Prendergast & Treacy, 2015).

Considering the challenges faced by each of the STEM subjects in post-primary education in Ireland, the responsibility for supporting STEM education at least partly reverts to institutions of higher education. Ireland has a comparatively high proportion of STEM graduates — 23% compared with the EU average of 9.3% (European Commission, 2004) and up until 2008 had benefited from growing state funding in order to help universities and other higher education institutions develop new scientific knowledge and drive innovation (Westhead & Storey, 1995). Due to the global financial crisis in 2008 and the subsequent recession, the Irish government made significant cuts to basic research funding and placed priority on "14 narrow areas" that have large global markets or suitability for Irish companies to be competitive (Butler, 2015). This has placed even more responsibility on higher education to help prepare young people for a competitive STEM environment as basic research in Ireland is not supported and does not offer structured career paths for early-career researchers. As Trinity College Dublin is the oldest and most influential institution of higher education in Ireland, it has the responsibility of leading by example and offering resources to actively support post-primary engagement with STEM subjects by developing an inquiry-based learning intervention called Trinity Walton Club.

Trinity Walton Club

Trinity Walton Club is an educational initiative of the School of Physics, the School of Education and the School of Mathematics at Trinity College Dublin. It was founded in 2014 with the objective of empowering post-primary students in STEM subjects through innovative teaching and an emphasis on collaboration and interdisciplinarity. Participants from across Ireland, but predominantly the greater Leinster area, come to Trinity College Dublin at weekends to partake in a semi-formal learning experience. The intervention strives to create a deeper understanding of STEM subjects, enhance skills and competencies, promote positive attitudes and beliefs, and unite like-minded learners with role models. The initiative is called Trinity Walton Club after Ernest Thomas Sinton (E. T. S.) Walton, the most decorated alumnus of Trinity's School of Physics and Nobel laureate for his work in splitting the atomic nucleus in 1932 (Cockcroft & Walton, 1932). He remains Ireland's only Nobel prize-winner in physics or chemistry.

Walton is an ideal role model for post-primary students due to his connection to Trinity College Dublin where he not only spent most of his career as a professor, but where he also completed his undergraduate studies and gained a double first in mathematics and experimental physics in 1926 (Finch, 2007). His superb experimental craftsmanship was highlighted by his PhD supervisor Ernest Rutherford at the University of Cambridge's Cavendish Laboratory even before he successfully split the atomic nucleus. Rutherford himself was also a Nobel laureate and one of the most important figures in nuclear physics (Allibone, 1973). Among his many contributions he discovered alpha particles — particles produced during radioactive decay consisting of two protons and two neutrons that are identical to a helium nucleus (Eisberg & Porter, 1961). The students participating in Trinity Walton Club refer to themselves as 'Alphas' to honour the importance of those alpha particles in the subsequent experiments of Walton. It was while working under Rutherford's supervision and after being paired with John Cockcroft that Walton was able to make his greatest contributions to science. Despite the fact that all three scientists were some of the greatest minds of the 20th century, it is noteworthy that they would likely not have made such telling contributions to scientific progress if they had not benefited from working together (Finch, 2007). This importance of collaboration is fundamental to the mission of Trinity Walton Club and is epitomised by achievements of Walton, Rutherford and Cockcroft (Figure 1).

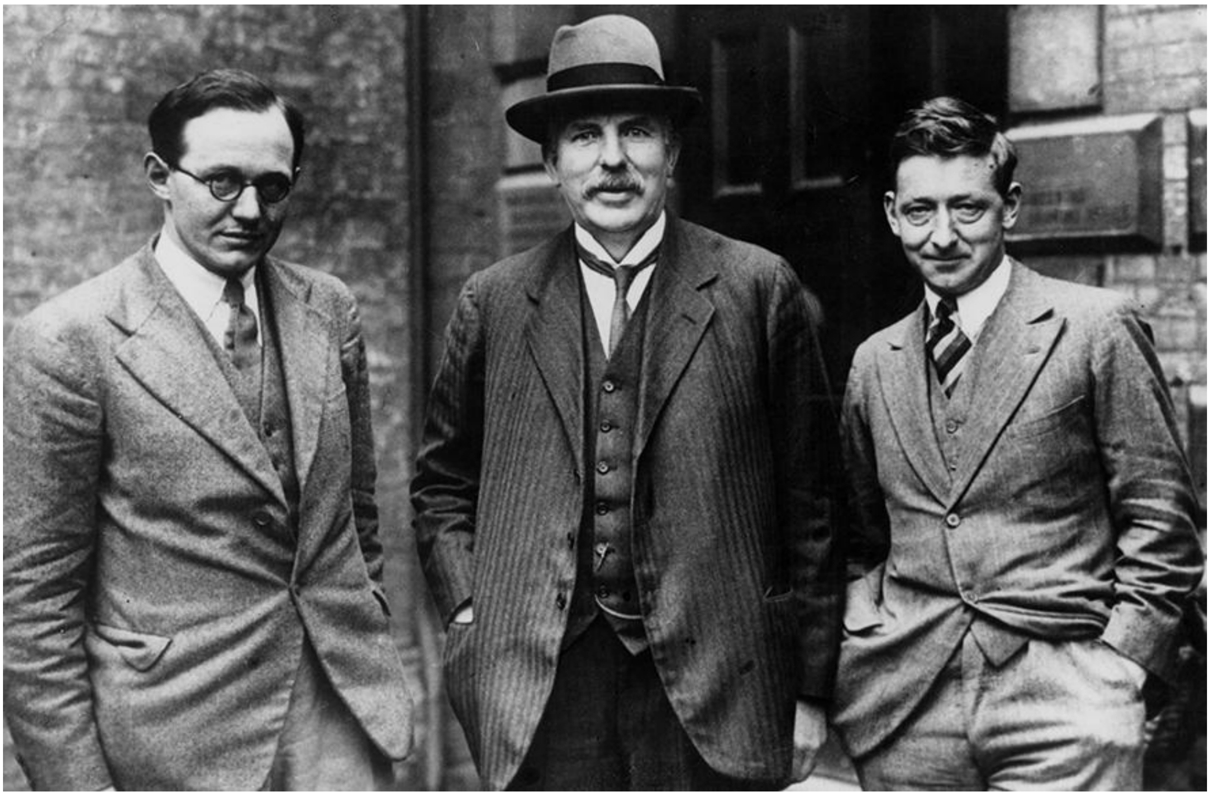

Figure 1. Walton, Rutherford and Cockcroft in 1932, shortly after they successfully split the atomic nucleus. Trinity Walton Club is named in honour of Walton while the students participating in the club refer to themselves as 'Alphas' in recognition of the alpha particles that were discovered by Rutherford and were critical to the experiments of Cockcroft and Walton. Credit: American Institute of Physics and the UK Atomic Energy Authority.

The club is hosted in the Physics Building in Trinity College — the first purpose-built physics laboratory in Ireland — opened in 1906 and named after G. F. Fitzgerald (O'Connor, 2014). Fitzgerald was a leading 19th century scientist and one of Ireland's most important physicists whose theory that space could be observed to contract when measured from reference frames approaching the speed of light were crucial to Einstein's theory of relativity (Bell & Weaire, 1992). The club is open to students that are in the second year of their post-primary school education. In the Irish system these students are typically between 13 and 14 years old. The club runs as a three-hour learning intervention once per week for ten weeks. There are three ten-week terms per year and the students are enrolled in classes of 25 individuals. The students self-select if they wish to join the club through an online application process. Their place on the course is awarded based on a personal statement that describes their interest in STEM subjects and their results in an entrance exam. Although a €750 tuition fee is required to cover staffing costs and teaching materials, a number of scholarship places are offered to students that demonstrate exceptional suitability for the club, especially if the school they are attending is in a disadvantaged community. The breakdown of participating students is shown in Table 1.

Table 1. A breakdown of the students that participated in Trinity Walton Club in 2014/15 and 2015/16. 'DEIS Schools' are schools in disadvantaged communities as designated by the Irish Department of Education and Skills (Molcho *et al.*, 2008).

	Trinity Walton Club Students	
	2014/15	2015/16
Total students	60	149
Students participating for the first time in the intervention	60	96
Studentsreturning for a second year in the intervention	-	53
Number of schools that engaged with the intervention	20	83
DEIS studentsparticipating	15%	15%

The club itself is an inquiry-based learning intervention. All the activities that students undertake in the club involve methods of learning that are driven by a process of inquiry where the tutor sets out a task and provides initial scaffolding to support the process but the students pursue their own means of inquiry, utilising their existing knowledge and identifying their own learning needs. While this inquiry-based learning approach can be traced back to the first iterations of problem-based learning (Barrows & Tamblyn, 1980) the curriculum design process for Trinity Walton Club was specific to inquiry-based learning in a 21st century context, mirroring the curriculum design process devised by Kahn and O'Rourke (2004). The design of the curriculum is undertaken by an academic advisory committee comprising researchers from Trinity's School of Physics, School of Mathematics and School of Education and focuses on problem-solving and critical thinking skills, in line with the 21st century skills and competences recommended for learners in OECD Countries (Ananiadou & Claro, 2009). While this approach has inherent benefits, some studies indicate that instructional approaches placing a stronger emphasis on guidance of the student learning process are more effective and more efficient than minimally guided instruction (Kirschner, Sweller & Clark, 2006). The inquiry-based learning approach is more student-centered, facilitates the learning of transferable skills and can improve the quality of teaching and learning but only when due consideration is given to the training needs of both the students and tutors (Deignan, 2009). The activities themselves are led by PhD researchers from all four of the STEM disciplines. These PhD researchers are recruited competitively based on their relevant experience and their passion for facilitating inquiry-based learning activities. They are responsible for facilitating the classes and ensuring that the participants have the support they need and guidance on how to undertake further work if necessary (Figure 2). The PhD researchers receive some training in facilitating inquiry-based learning activities, and meet regularly to reflect on teachings. They are tasked with recognising when students have enough prior knowledge to tackle the activities by themselves and when they might be in need of more structured guidance with their learning.

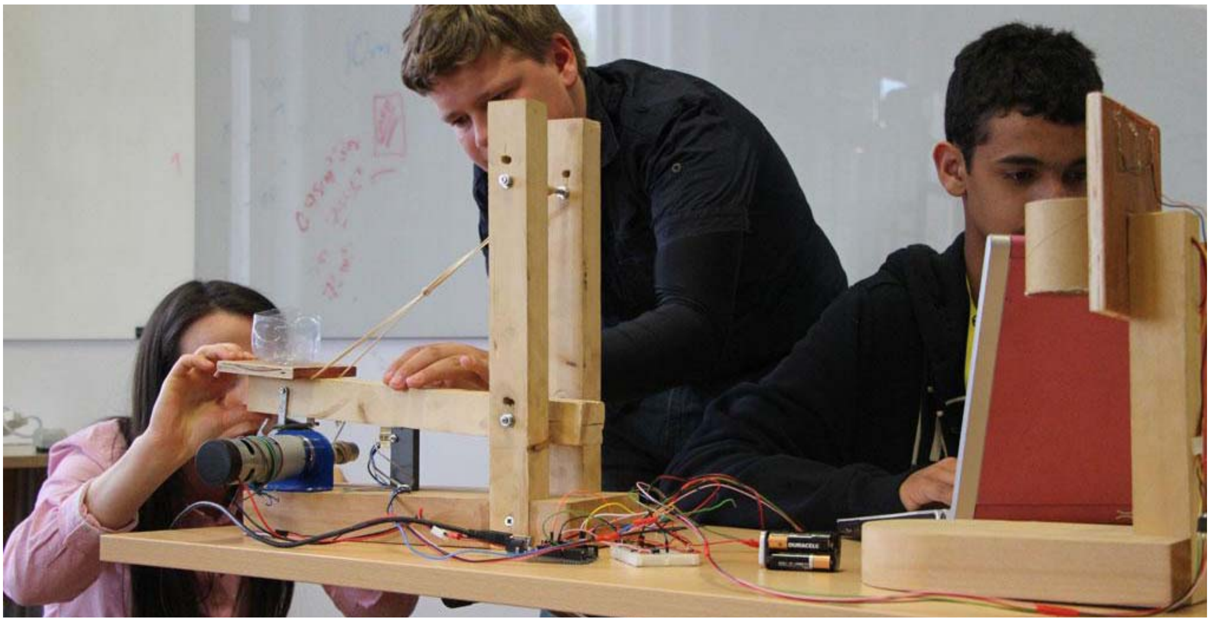

Figure 2. An example of an inquiry-based learning activity in Trinity Walton Club. The students are tasked with creating a trebuchet to simulate the catapulting motion central to the popular smartphone game 'Angry Birds' (MacIsaac, 2011). This activity conveys key properties of engineering (McGrew, 2012), especially kinematics and dynamics (Rodrigues & Carvalho, 2013) and is a modern way of integrating popular smartphone games into STEM education (Hudson, English & Dawes, 2012).

The activities at the club are always group-based and are supplemented by social activities such as tours of the university and visits to research labs in order to meet both the scientists, technologists, engineers and mathematicians that typically work at a university. The students work on STEM projects that they subsequently exhibit at an end of year showcase. The 'club' format is crucial as it allows the intervention to exist in the space between formal and informal education. While the content that is taught supports the post-primary curriculum, it does not face the same assessment constraints. This means the advisory committee and the PhD researchers have the freedom to experiment with innovative teaching methods that are more suited to a true 21st century STEM education. The semi-formal nature of the intervention means that the students' learning experiences aid their preparation for state examinations as well as any national or international STEM competitions that they might choose to compete in. The intervention also develops their skills and confidence to study STEM subjects in higher education.

Conclusions

The global rise in initiatives supporting education in the areas of science, technology, engineering and mathematics has seen the term 'STEM education' become increasingly common in formal education. In Ireland, a unique set of challenges to post-primary STEM education has made it difficult for young people to achieve their potential in STEM subjects at post-primary level. Trinity College Dublin has developed an inquiry-based learning intervention to support post-primary engagement with science, technology, engineering and mathematics. The intervention is in its second year and has supported 151 students in post-primary schools from the across the greater Leinster area.

Trinity College Dublin is well-placed to offer an inquiry-based learning intervention to support post-primary engagement due to its ongoing commitment to improving and supporting STEM education at all levels. It has already undertaken initiatives to try and help reform STEM education in post-primary schools by offering a Postgraduate Certificate in 21st Century Teaching & Learning which is funded by Google Ireland and will see more than 1,000 post-primary school teachers receive continuous professional development in STEM subjects and computer science between 2014 and 2017 (Roche, 2014). Trinity College also offers masters courses that facilitate post-primary school teachers undertaking research to ensure better practice in science and mathematics education (Roche & Prendergast, In Review). Trinity Walton Club is the university's first foray into directly supporting the students themselves during post-primary education.

Although this intervention is the first of its kind in the Irish education system, there are several limitations that must be taken into account. Despite the resources of Trinity College Dublin, this intervention can only reach a small fraction of the total post-primary student population that might be interested in pursuing STEM subjects at university-level. The entry requirements to take part in the intervention mean that Trinity Walton Club is already biased towards enrolling students that have demonstrated a natural aptitude for engaging with STEM subjects at an early stage of their post-primary education. While it is likely that the intervention will strengthen that engagement, it will have almost no way of supporting students that develop an interest in STEM subjects later in their post-primary education.One way of addressing this is the introduction of Trinity Walton Club 10-day camps which will give older post-primary students the opportunity to engage in condensed versions of the intervention.

The next step in this work will be carrying out a comprehensive evaluation of Trinity Walton Club and its impact on the students involved. Trinity Walton Club will continue to enrol students from new schools over the coming years which will broaden the demographic of the students and expand the geographical catchment area beyond Dublin and some of the surrounding counties. An important stage of this research will be determining if the students that have participated in Trinity Walton Club have higher levels of engagement with STEM subjects at university-level than their peers that do not take part in the intervention. Each year of the intervention the students that take part provide feedback to help identify the most effective and less effective aspects of the intervention. End of term questionnaires as well as interviews and classroom observations carried out by independent STEM education experts will provide part of the evaluation, while the eventual paths taken by the students into higher education will be monitored to assess if involvement in Trinity Walton Club does indeed lead to better engagement with STEM subjects at university-level. To allow for additional factors that might affect the general student population's engagement with STEM subjects, national averages will be used as comparisons to the results gathered from students taking part in the intervention. As the intervention is free from the constraints of formal education, continuous evaluation will allow new approaches to teaching and learning strategies to be developed and improved on successive iterations of the intervention, increasing the chances of providing true innovation in STEM education. Other Irish institutions of higher education will be invited to contribute to this work, either by collaborating on the current intervention or by helping to develop their own version. Finally, the outcomes of this intervention will have to be put in an international context. This could potentially be accomplished by taking the inquiry-based learning activities developed for this intervention and testing them in other European countries through the support of an Erasmus+ project designed to share best practices.

While this paper demonstrates the need for higher education institutions to offer support to post-primary STEM education, and describes a subsequent inquiry-based learning intervention hosted at Trinity College Dublin, the authors feel this is only the start of the work needed for institutions of higher education to tackle some of the current problems facing STEM education. It is hoped that the work demonstrated here will inspire other institutions to consider becoming involved in meeting the challenges of 21st century post-primary education.

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