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Connecting Research, Policy and Practice in STEM Education

Proceedings

8th Science and Mathematics Education Conference (SMEC)

hosted by the
Centre for the Advancement of STEM Teaching and Learning (CASTeL)
Dublin City University
25th - 26th June 2018.

Publisher: Centre for Advancement of STEM Teaching and Learning, Dublin City University

ISBN 978-1-873769-91-1

Introduction

The eighth biennial Science and Mathematics Education Conference (SMEC) hosted by the Centre for the Advancement STEM Teaching and Learning (CASTeL) was held at Dublin City University on 26th June 2018. A special focus of this year's conference was to provide a forum for young researchers in STEM education and an inaugural Early Career Researchers' day was held on 25th June 2018.

SMEC2018 is the eighth in a series of biennial Science and Mathematics Education Conferences hosted by CASTeL. The purpose of this conference series is to provide a platform for teachers and educators to discuss practices and share their experiences in the teaching and learning of mathematics and science. Previous conferences have focused on the following themes: Teacher Education; Inquiry-based learning; Assessment; Facilitating authentic learning; Sciences serving science; and Exploring the interconnections between STEM subjects.

The recent STEM education policy statement 2017 - 2026 (Government of Ireland, 2017) recommends the enhancing and embedding of existing good practice in STEM Education and calls for attention to establishing what is necessary to provide a quality STEM education experience. In this context, the theme for the 2018 conference was *Connecting Research, Policy and Practice in STEM Education.*

Organising Committee

Dr. Siún Nic Mhuirí (Chairperson)

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Keynote Speaker 1: 09:15, Heaney Theatre, G114

Professor Merrilyn Goos

Director of EPI*STEM, University of Limerick

Merrilyn Goos is Professor of STEM Education at the University of Limerick, and Director of EPI*STEM – the national Centre for STEM Education. Previously she was Professor and Head of the School of Education at The University of Queensland. She has also worked as Professor of Mathematics Education at Loughborough University, UK. She is an internationally recognised mathematics educator whose research is well known for its strong focus on classroom practice. Her research interests include students' mathematical thinking, the impact of digital technologies on mathematics learning and teaching, numeracy across the curriculum, and the professional learning of mathematics teachers. She is currently Vice-President of the International Commission on Mathematical Instruction and Editor-in-Chief of Educational Studies in Mathematics, one of the leading research journals in mathematics education. She has also gained national recognition as a mathematics teacher educator, having won an Australian Award for University Teaching in 2004 as the most outstanding teacher in the social sciences disciplines. She is the lead author of two teacher education textbooks on Teaching Secondary School Mathematics and Numeracy Across the Curriculum – the latter of which is due to be published later in 2018.

Merrilyn's keynote address is entitled:

Research that makes a difference: Why impact matters

Research that makes a difference: Why impact matters

Merrilyn Goos

University of Limerick

While measures of research quality are widely accepted in the education research community, there may be less agreement on what constitutes evidence of impact and on where to look for this evidence. This presentation considers the most common rationale for demonstrating impact, compares definitions of research impact in use in Ireland and Australia, and illustrates what engagement and impact can look like in two case studies of STEM education research conducted in Australia. The first case study is a well-established research program for embedding numeracy across the whole school curriculum. The linear logic models promoted by research funding bodies cannot capture the complexity of this type of education research, and so alternative representations are used to map the growing networks of engagement and impact over an 18 year period. The second case study is a large scale, 6 month project commissioned by the Australian government to identify characteristics of best practice in mathematics education based on student performance on national standardized tests. Despite its inherent design flaws, this project yielded insights into the potential for this type of research to generate productive engagement with policy makers. Nevertheless, questions remain as to how the findings could be used to improve teaching practice and student learning. These case studies suggest that retrospective analysis of our own research can point to "where to look" for evidence of past impact, and help us anticipate the impact of future projects.

Keynote Speaker 2: 2:00, Heaney Theatre, G114

Professor Anna Steinweg,

University of Bamberg

Anna Steinweg is Professor of Mathematics and Computer Science Education in the University of Bamberg, Germany. She is the Vice-Dean of the Faculty of Human Sciences and Education and holds the position of Head of the Bamberg Centre of Teacher Education. She is an internationally recognised expert in mathematics education, and researches in the areas of early mathematics and early algebra in particular. She is currently the editor of 'Mathematikdidaktik Grundschule - Proceedings of Conferences of the Research Group on Primary Mathematics Education' and is a reviewer for Educational Studies in Mathematics. In her keynote, she will provide a context for her own research by discussing design research and the German approach to STEM education (MINT initiatives) more generally.

Anna's keynote address is entitled:

Quality Enhancement in Mathematics Education: Some Insights into German Initiatives and Research

Quality enhancement in mathematics education: Some insights into German initiatives and research

Anna Susanne Steinweg, University of Bamberg
anna.steinweg@uni-bamberg,de

Research in Mathematics Education always aims for improvement of mathematics lessons in order to enhance children's development in mathematical thinking. Different approaches to achieve this objective can be observed in national and international research. In the talk my own idea of reasonable research is offered to reflect upon. Of course my research is influenced by the national circumstances in Germany.

The two-part talk first addresses the German education system and initiative introduced by policy makers. Some information on the impact and evaluation results are presented. In the second part insight into my own research is given. Exemplarily current projects in the field of early mathematics education (Birklein & Steinweg, 2018) and algebraic thinking (Steinweg, Akinwunmi & Lenz, 2018; Steinweg, 2017) are briefly described.

All my projects have in common that the starting point is identifying key ideas. They serve as designing principles for adequate material, tasks, and learning environments. Implementing the designed tasks in schools allow teachers to become aware of key ideas -the main topics of a content area- and therefore guide classroom interaction. Moreover, exploring and regarding children's competencies in the certain content area is an important element. Only in relation to these abilities the evaluation of the designed material and learning environments can be refined and improved.

Keywords: design research, key ideas, German maths education initiatives, early mathematics, algebraic thinking

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Steinweg, A., Akinwunmi, K., & Lenz, D. (2018). Making Implicit Algebraic Thinking Explicit: Exploiting National Characteristics of German Approaches. In C. Kieran (Ed.), *Teaching and Learning Algebraic Thinking with 5- to 12-Year Olds: The Global Evolution of an Emerging Field of Research and Practice* (pp. 283-307). Cham, CH: Springer International Publishing.

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Keynote Speaker 3: 4:30, Heaney Theatre

Professor Deirdre Butler

Centre for the Advancement of STEM Teaching and Learning (CASTeL)

Dublin City University

Deirdre Butler is Professor of Education in Dublin City University (DCU) Institute of Education. Deirdre has extensive experience in developing sustainable, scalable models of teacher professional learning, and has managed projects and school based initiatives which focus on creative uses of digital technologies. She is internationally recognised as a leading scholar and expert in learner-centered pedagogical approaches. She has advised both Finish and Danish policy makers on the on the redesign of learning environments. Establishing strategic partnerships has been a key feature of Deirdre's work and a number of impactful initiatives have resulted from her collaborations with Microsoft, Business Model Adventures, the National Institute of Digital Learning (NIDL) and H2 Learning. Deirdre was also instrumental in the establishment of the flagship Lego Education Innovation Studio in the DCU Institute of Education. Recently, she won the DCU President's Award for Engagement –Special Award in Enterprise Engagement.

Deirdre's keynote address is entitled:

STEM - The whole is greater than the sum of its parts

Teacher and student experience of inquiry in the context of socioscientific issues in Irish junior cycle science

Ruth Chadwick[1], Odilla E. Finlayson[2] and Eilish McLoughlin[1]

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Inquiry as an approach to teaching science is student-centered and collaborative and can facilitate students being involved in conducting investigations, including experimentation and secondary research. When inquiry is carried out using socioscientific issues (SSI) as the context a range of skills relating to research and critical evaluation of evidence may be developed and assessed. The Irish Junior Cycle Science in Society Investigation asks students to carry out a research-based inquiry exploring SSI contexts and it aims to develop and assess a range of skills and knowledge of science. This paper discusses the recommended approach to the Junior Cycle Science in Society Investigation as outlined by Ireland's National Council for Curriculum and Assessment (NCCA). The paper also makes some general comments and recommendations regarding the outlined teaching approach, SSI contexts and skills and knowledge to be developed and assessed.

Keywords: Inquiry, Socioscientific Issues, Irish Junior Cycle

INQUIRY AND SSI CONTEXTS

Inquiry as an approach to teaching involves students engaging in student-centered activities and active-construction of learning (Colburn, 2000). Collaboration and discussion during inquiry-based activities allow students to exchange ideas and the teacher acts as a facilitator, asking relevant questions and encouraging students to reflect on their understanding (Colburn, 2000; Harrison, 2015). During inquiry-based lessons in science classrooms, students carry out investigations, including experiments and secondary research (Wenning, 2005).

Socioscientific Issues (SSI) are controversial, scientific topics with societal implications, which may be used to provide contexts for student inquiry (Sadler, 2009). SSI are controversial, meaning they involve a range of viewpoints, which may conflict with the students' own views. (Oulton, Dillon & Grace, 2004). SSI provide a context for experimentation and investigation, at the same time providing opportunities for dialogue, discussion and debate. However, there is likely to be less focus on experimental investigative approaches and more on explanations of science (Sadler, 2009; Zeidler & Nichols, 2009). Students engage in interpretation, analysis and evaluation of conflicting data and evidence from a range of sources (Zeidler et al., 2009). They are also likely to use information literacy skills to identify, access and evaluate sources of evidence (Julien & Barker, 2009). SSI may encourage students to prepare for and engage in socio-political actions that they believe will make a difference to the local or global situation (Hodson, 2010). Students may carry out socially and environmentally responsible actions based on their inquiry. For example, they may choose to educate others, boycott offenders, lobby power brokers or improve personal actions (Bencze, 2017, p. 34).

THE IRISH JUNIOR CYCLE SCIENCE IN SOCIETY INVESTIGATION

In Ireland the Junior Cycle Science in Society Investigation is proposed to take place for the first time in Autumn/Winter of 2018. In this assessment students carry out inquiry into SSI contexts. The prescribed teaching approach, SSI contexts, and skills and knowledge that the Science in Society Investigation aims to develop and assess are described by the NCCA in the

Guidelines for the Classroom-Based Assessments and Assessment Task (NCCA, 2016) and the *Curriculum Specification* (NCCA, 2015).

This paper aims to briefly outline the intended approach to the Junior Cycle Science in Society Investigation, as outlined by the NCCA (2015; 2016). It will discuss the recommended teaching approach, SSI contexts and skills and knowledge the assessment aims to develop and assess. It will also present some recommendations for implementation of inquiry in the context of SSI in Ireland.

Teaching approach

The Science in Society Investigation is expected to be carried out over three weeks of class time, in three stages: initiating research, communicating findings and evaluating. The initiating research stage may be carried out collaboratively while the communication and evaluation stages are expected to be carried out individually (NCCA, 2016). Collaboration is described by the NCCA (2016) as discussing various aspects of the investigation in small groups.

- During the first stage, initiating research, the student chooses the topic for investigation, decides a specific research question, and gathers and records information through secondary research (NCCA, 2016).
- In the second stage, communicating findings, the student selects information from their sources of evidence relevant to developing a response to their question for investigation (NCCA, 2016).
- In the final stage, evaluating information, the student develops a personal opinion relating to their chosen research question. At this stage, students work individually to compile a report of their investigation (NCCA, 2016).

The NCCA describes the way in which teachers should facilitate all stages of the assessment as "reasonable support" (NCCA, 2016 p. 8). Students should be encouraged to show a "level of initiative" but teachers can support students by clarifying the requirements of the task, providing exemplars, providing instructions at strategic intervals and providing supports for students with special educational needs (NCCA, 2016, p. 9).

Student choice is emphasised as a motivating factor for all stages of the assessment and students choose their own topic (initiating research stage), the format of the report (communicating/ evaluating findings) and the extent to which collaboration is used (initiating research stage only) (NCCA, 2016, p. 23). In this way the assessment can be changed according to the needs, contexts, and circumstances of the students (NCCA, 2016). The NCCA (2016) emphasises the importance of student and teacher preparation in years one and two of secondary school in preparation for the Science in Society Investigation in third year (NCCA, 2016).

SSI context

The NCCA (2016) recommends that students choose their own topic for investigation with the aim of increasing personal and local relevance. The topic is described as a scientific topic and its impact (positive or negative) on society and/or the environment (NCCA, 2016, p. 26). Topics that have a range of points of view are encouraged. The NCCA provides the following set of criteria for choosing the topic for investigation:

> Is this topic course-related, an issue of personal interest, or one with local relevance?
>
> Can the topic be researched?
>
> Is there a sound base of scientific understanding and ideas?
>
> Are there two or more sides to the story?
>
> Can it be turned into a specific research question?
>
> (NCCA, 2016, p. 37)

Using these criteria, the NCCA (2016) clearly aims to direct students towards choosing SSI contexts. These criteria ensure that the topic has societal or environmental implications but also relevant underlying science. Ensuring the topic has multiple points of view relates to the controversial nature of SSI. Suitable topics can be researched and have research questions associated with them.

The NCCA (2016) provide two exemplar topics that aim to fit the criteria given above. The first topic investigates the technological application of nuclear power plants and their societal and environmental impact. The second topic explores the technological application of electronic passports and their societal implications.

Skills and knowledge developed and assessed

The NCCA discusses the skills and knowledge that the Science in Society Investigation aims to develop and assess. The inquiry "should be viewed as part of teaching and learning, and not solely for assessment purposes" (NCCA, 2016, p. 8) and as such should be considered to develop, as well as assess skills and knowledge of science.

In the initiating research stage, the students are assessed on their performance in the following: Choosing a topic and research question, finding information about the topic from a range of sources and including a reference list, evaluating the reliability (relevance, accuracy and bias) of the sources and considering the quality of the information collected (NCCA, 2016, pp. 31-32). Students will be assessed on their ability to choose a clearly defined research question based on scientific knowledge ("background reading"). This question need not be set in stone at the start of the inquiry but can be changed and refined as the research progresses (NCCA, 2016). Students will also be assessed on their ability to research. They should gather and record evidence relating to their research question from the internet, newspapers, science journals or magazines etc. Students are asked to record the source of all evidence and evaluate sources in terms of reliability, relevance, accuracy and possible bias (NCCA, 2016). They are also encouraged to carry out their own primary research such as a "survey to support their research" or "experimental investigation" although this is not a requirement (NCCA, 2016, p. 27).

The skills relating to the communication stage are: Positioning the topic as science in society, explaining the relevant science and the impact of the topic on society and/or the environment, presenting the investigation in a structured, clear and easy to read way, using scientific terminology and representations, using an innovative approach and explaining different sides of the argument (NCCA, 2016, pp. 31-32). Students are assessed on their ability to communicate and explain the findings of their primary and secondary research by selecting relevant information from their sources of information and data, e.g. written text, audio/visual, charts, survey responses and diagrams (NCCA, 2016). The student is assessed on their ability to explain the topic in their own words and credit is given for situating explanations within the SSI context. The NCCA describes how students should "position the topic as science in society and discuss the impact of the topic on society and/or the environment" and discuss the "personal or local relevance" and the "different viewpoints and sides of the argument" of the SSI context (NCCA, 2016, p. 31). Scientific knowledge is expected to be used when communicating the findings.

In the final stage, the evaluation stage, students are assessed on their ability to: Evaluate information, consider and discuss their own view on the chosen topic, link the information to the topic, review the information by giving scientific explanations, and give a personal opinion that is justified by the information in the report (NCCA, 2016, pp. 31-32). Students are assessed on their ability to evaluate the researched information. They are assessed on their ability to comment on agreement or disagreement between sources of evidence and make judgements about how the information supports or does not support their chosen research question.

Students are then expected to state a personal opinion based on their research and justified with scientific knowledge. Assessment of these skills directly relates to exploration of SSI contexts as they relate to the multiple viewpoints and the inability to reach finite conclusions inherent in SSI contexts.

COMMENTS AND RECOMMENDATIONS

The following paragraphs contain recommendations for the NCCA curricular policy relating to the Junior Cycle Science in Society Investigation.

In the NCCA's (2016) Science in Society Investigation (NCCA, 2016) the skills focus is on secondary research, critical evaluation of evidence and giving scientific explanations of the implications of science for society, using scientific knowledge. It is promising to see a high emphasis placed on exploration of SSI contexts and the skills relating to this and this is reflected in the assessment criteria. Students are rewarded for choosing an "interesting" or "novel" topic. They are rewarded for positioning the topic as "science in society" and discussing the impact on society. They are rewarded for discussing different sides of the argument and rather than a finite conclusion, the student is expected to give a "personal opinion".

The student's role in each stage of the assessment is defined by the NCCA in terms of the extent of collaboration used and skills and knowledge to be developed and assessed. However, from the NCCA's description it is unclear where the distinction is drawn between the second and third stage of the assessment. While the second stage is called "communicating findings", it is in the final stage that they compile their report (NCCA, 2016). Additionally, the NCCA (2015; 2016) doesn't clearly distinguish the varying role of the teacher in the different stages. It is recommended that the pedagogical approach to the stages of the assessment are clearly defined. As well as stating the skills that students will develop at each stage, the teacher's role should be discussed. This will help the teachers understand the intended teaching approach to the assessment.

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Enhancing student conceptual understanding of energy using process drama as a conceptual metaphor

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The use of process drama as a conceptual metaphor allows for 'reverse cognitive processing' to happen, providing unique hinge-points in learning for students. This can allow the student to consider complex issues differently, positioning the learner differently, influencing the way engagement and learning can happen (McGregor & Precious, 2014). This study focuses on improving students' inclusion and engagement in science and in particular on conceptual understanding of energy, a complex cross-cutting science topic, through the use of drama as a conceptual metaphor in teaching, learning and assessment processes. The design of the research and pedagogical framework developed that addresses conditions required for conceptual change and sequence of learning progression for Energy concepts this study is presented, along with its use for initial analysis of student responses to pre- and post-questionnaires.

Keywords: Process drama, conceptual metaphor, reverse cognitive processing, conceptual change.

INTRODUCTION

Energy is an important scientific concept and has a central significance in all sciences. Energy, is significant not just in a scientific context but it is also associated with various everyday events and is frequently in the media because of its socio-economic and environmental relevance, which includes such issues as, climate change, renewable energy sources, nuclear energy and health issues among globally-significant areas (Opitz et al., 2015). In Lancor's study exploring students' conception of energy and the metaphors students use for teaching energy, the term energy is 'defined and utilised in different ways, depending on the context, even within a given discipline' (Lancor, 2012). Lancor highlights that energy is conceptualised differently in different scientific contexts and that varying conceptual metaphors of energy 'highlight and obscure characteristics of energy' (Lancor, 2012). Optitz observed that "as students mature … they exhibit neither a discipline-specific differentiation of their energy understanding, nor a process of integration that combines discipline-specific sets of energy understanding into a cross-disciplinary energy concept" (Opitz et al., 2017). This suggests that energy concepts are not understood in any connected way, across the broader scientific disciplines. Hence teaching complex concepts like energy conservation, can benefit from alternative instruction approaches, e.g., the use of spatial representations in learning is reported to improve memory and understanding (Scherr et al., 2011) and process drama to position learners differently in the learning environment to enhance understanding and conceptual change.

THEORETICAL BASIS

We all naturally experience the physical world through sensory-motor experiences, which helps us make sense of the world around us. This is a holistic and organic process. Learners can also use conceptual metaphors to express their understanding verbally, of complex scientific concepts. The *reverse-cognitive processing* that process drama, as a conceptual metaphor, activates, allows the learners' developing ontology, to be revealed, making it available for examination, negotiation and refinement (Scherr et al., 2010). Reverse cognitive processing is also described as 'differentiation and integration, to restructure knowledge' (Close & Scherr, 2011).

The use of process drama, as a conceptual metaphor in teaching science concepts has gained much interest as such methodologies are reported to improve students' engagement and understanding in science. Process drama is a dynamic teaching methodology that creates an imaginary dramatic world to explore a particular problem for the benefit of the participants and not the audience. Conceptual metaphor theory proposes that the mind creates abstractions from sensory-motor experiences which fundamentally are *image schemas* in our brain, which become reference domains from which learning and understanding happens. (Lakoff & Johnson, 1980). The use of drama to teach science is described as a constructivist and productive teaching method (Braund, 2015). Process drama is a dynamic teaching methodology that creates an imaginary dramatic world to explore a particular problem for the benefit of the participants and not the audience (O'Neill, 1995). Drama, whether in theatre or being used as a teaching tool in science, 'both seek explanations of the world through real, imagined or vicarious experiences' (Fels & Meyer, 1997, p. 75). The use of process drama as a conceptual metaphor allows for *reverse cognitive processing* to happen, where complex science concepts are experienced, initially through physical sensory-based activities, stimulating cerebral cognitive processes, providing unique hinge-points in learning for students. This is an alternative approach to teaching difficult science topics and to facilitate research into learning strategies that can allow the student to consider complex issues through the sensory processes, positioning the learner differently, and exploring the benefits of alternative ways of engaging in learning, that could bring about conceptual change for any learner. The immersive effect of process drama, into the sensory-world of alternative learning experiences, allows learners to improvise and to be creative in how they interpret their experiences of scientific concepts and avoid over-assigning meaning to representations.

Using process drama as a conceptual metaphor, in teaching, learning and assessment processes in the classroom, is important because of its role in designing learning that can potentially enable conceptual change in understanding of difficult science topics like energy concepts. The use of a 'blended learning space' to develop understanding of energy concepts, using body movement, gestures and metaphorical speech or 'energy theatre' as described by Close and Scherr (2015), is similar to the use of process drama as a conceptual metaphor for learning.

METHODOLOGY

In this study the potential of process drama as a teaching methodology, to change students' conceptions or misconceptions about energy concepts, is examined. Using process drama as a conceptual metaphor, allowed the student to create abstractions from sensory-motor experiences which promotes learning and understanding. The process drama example used in this study examined the energy flow in a chemical reaction, specifically the combustion of methane gas, an organic carbon-based fuel and first member of the organic family, the alkanes (see Figure 1. The chemical reaction is explored in terms of four energy concepts; energy form/source, energy transfer and transformation, energy degradation and dissipation and energy conservation.

$$CH_4 + O_2 = CO_2 + 2H_2O$$

$$\text{Methane} + \text{Oxygen} = \text{Carbon dioxide} + \text{Water}$$

Figure 1: Chemical reaction for the combustion of methane gas.

In particular, the aim of this research is to examine to what extent does the use of *process drama as a conceptual metaphor* enhance student learning of energy concepts, by considering:

- The influence of the learning context of the energy concepts
- Conceptual change and improvement in conceptual understanding of energy concepts
- Evidence of improved student engagement and participation in the classroom

Figure 2 presents an overview of the pedagogical approach developed in this research study. Three classroom activities were designed - (1) Combustion Dance, (2) Story Board and (3) Video Capture - that used an imaginary dramatic world (O'Neill, 1995) and provided an experiential space for learning (Braund, 2015). Qualitative and quantitative data was collected at various stages during the lesson implementation. Three student worksheets were used before the start of activities 1-3, and five post-implementation tools were used including two online multiple choice questionnaires and production of videos and story boards. The pre- and post-questionnaires used a combination of multiple choice questions and open-ended questions based on the IDEA measuring assessment tool (Park & Liu, 2016) and a Multiple Choice instrument developed by Opitz et al. (2017). Teacher observations of student's responses and engagement in classroom discussion were also recorded.

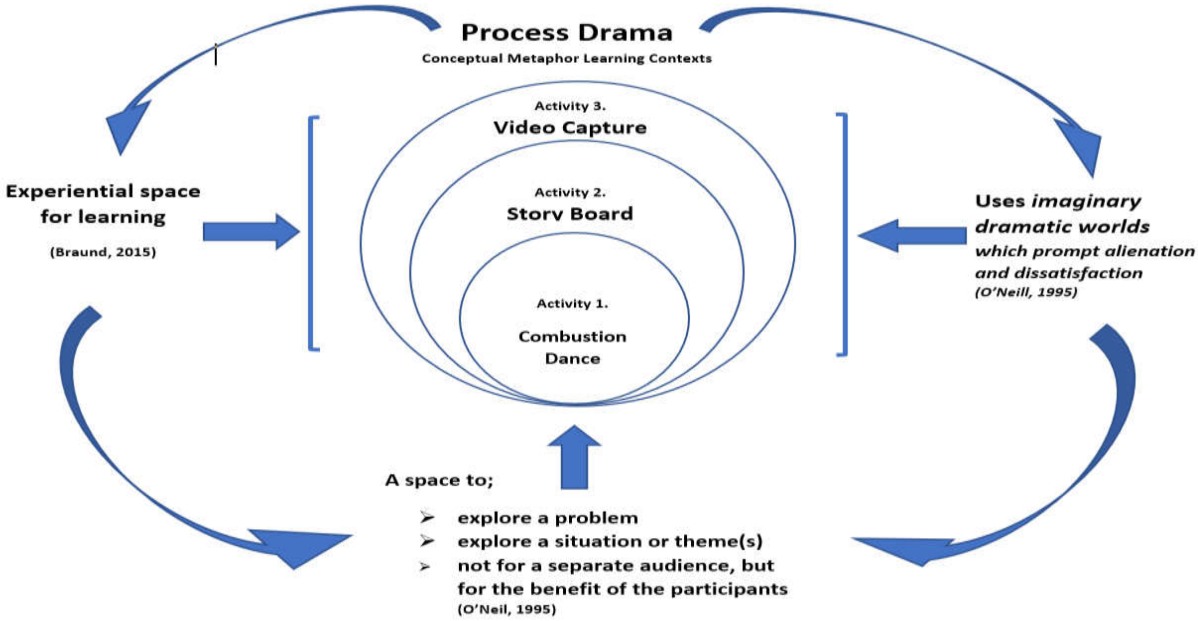

Figure 2: Overview of the pedagogical approach developed in this study

The focus of this study is to develop a pedagogical framework for teaching energy that adopts dance as a process drama as a conceptual metaphor. The participants are second level students (aged 13-14 years) that are completing a three-year integrated Science Curriculum in Ireland, where Energy is identified as "*A unifying concept that students can develop across the strands: it is an obvious integrating element as all phenomena we observe on earth and in space involve the transformation and variation of energy*" (NCCA, 2016).

FINDINGS

The first step in this study was to identify distinct conceptual understanding statements (CUS) for the concept of Energy that were aligned with the expected student learning outcomes for students completing the NCCA Junior Cycle Science Curriculum (NCCA, 2016). Table 1, page 16, presents the 26 statements identified and used in this study.

Evidence of student conceptual change was examined based on Posner's guide for conditions needed for conceptual change to happen (Posner, 1982). The four conditions needed for conceptual change, dissatisfaction, intelligibility, plausibility, and fruitfulness, were aligned with the learning progression sequence required for development of understanding energy concepts. The progressive sequence of energy concepts used identified four areas (1) energy forms/sources, (2) energy transfer and transformation, (3) energy degradation and dissipation (4) energy conservation where (1) requires lower order thinking and (4) requires higher order thinking (Opitz et al., 2017). The pedagogical framework developed in this study is presented in Table 2, page 17, and maps the 26 conceptual understanding statements (CUS) of Energy across the four areas of the learning progression sequence and the four conditions for conceptual change to occur.

To examine if process drama can be used as a conceptual metaphor to promote conceptual change in understanding of energy concepts, coding of student responses from pre-questionnaires was carried out. The numerical mapping tool, outlined in Table 3, was used to identify conceptual change within and across the energy concepts, where the higher the CUS number, represents evidence for improved conceptual change and higher order thinking.

Table 3: Summary of pedagogical framework relating conceptual change to learning progression in energy concepts.

Conditions for Conceptual Change	**Energy Concepts Progression Sequence**			
	E1	**E2**	**E3**	**E4**
C1	CUS 1 – 3	CUS 9 - 11	CUS 16, 17	CUS 21 - 23
C2	CUS 4, 5	CUS 12, 13	CUS 18	CUS 24
C3	CUS 6, 7	CUS 14	CUS 19	CUS 25
C4	CUS 8	CUS 15	CUS 20	CUS 26

The sample of work (from student 7) shown in Figure 3, page 18, presents the responses from student 7 and coding applied based on CUS. The focus of the questions included in pre-test 1 and post-test 4 examined changes in conceptual understanding in **distinguishing between energy and matter in a chemical reaction/equation.** In the pre-test 1, student 7 could *not* clearly distinguish between energy and matter and refers to one of the reactant molecules (methane) as energy and the other reactant molecule (oxygen) as matter (CUS 1). In post-test 4, student 7 shows evidence of change in conceptual understanding by selecting the multiple choice '*Some energy is held in bonds in the molecules, the rest was released as heat or light. All the molecules represent matter*' and was able to express this conceptual understanding in her own words (CUS 6).

Table 1: Conceptual understanding statements (CUS) developed in this study

1. Students employ single objects to describe energy forms/sources and disregard a system-based approach, in many energy contexts e.g. wind energy.
2. Visualising energy flow, forms and sources related to plants as primary producers of energy from the sun, where plants use sun, chlorophyll, water, carbon dioxide and nutrients, to manufacture glucose, a primary source of energy for living things, is challenging.
3. Energy concepts involve micro-macro, atomic-molecular and quantum-mechanical perspectives e.g. the use of the ideal gas law $PV=nRT$, to measure microscopic energy properties of a system, is a complex concept.
4. Energy exists in many forms, as either potential or kinetic. Chemical energy is stored in bonds, in atoms or molecules. Bond formation results in more stable molecules, with lower energy. Elements bond together to give different molecules, and sources of energy e.g. hydrocarbons, like methane.
5. Students must distinguish between energy forms and states of matter, where energy causes matter to change state, while energy comes from matter.
6. Distinguishing between physical examples of energy forms and sources, is useful. For example;
   forms: light, heat, potential, kinetic
   sources: fossil fuels like methane gas, heating oil, coal.
7. The chemical structure of sources can differ in bonding which can affect function and amount of activation energy required.
8. Classification of energy forms/sources as diverse, renewable or non-renewable matter is determined from measurement and extraction processes, application and uses of different energy forms, and factors that influence this.
9. Heat and light is used to describe energy transfer in a chemistry context, whereas heat is seen as a by-product and indicator of inefficiency in a physics and biology context.
10. Reactants and products in a chemical reaction are often confused as both the energy and the matter in a system.
11. Energy transformation can involve complex chemical processes, e.g. in living organisms, plants use structures called chloroplasts and animals use mitochondria, as cellular energy factories, to handle energy transformation processes, to meet their energy needs.
12. Energy transfers through systems, in different forms, as seen in a food chain: sun energy > chemical energy > heat energy etc.
13. Activation energy must be reached first, usually coming from an outside source, before a chemical reaction will start.
14. Understanding the concept of energy in different science contexts, like in biology, chemistry or physics, is useful and achievable through observing physical events representing energy transfer, like melting, evaporation, burning (combustion) and mass change in plants and animals involved in a food chain.
15. Measurable features of aspects of energy transfer can lead to understanding of processes involved, that give the changes observed, like melting, evaporating (state change) and burning (combustion), heat and light and contribute to understanding.
16. Students struggle with connecting events involving energy processes, where materials break down, recycle, as well as how they are formed, in both the natural and synthetic world.
17. Entropy is a thermodynamic quantity representing the amount of energy in a system, that is no longer available for doing mechanical work. It is also a measure of the molecular disorder or randomness of a system.
18. Many practical examples of energy recycling exist in the natural world, e.g. the water cycle, the carbon and nitrogen cycles, as well as the degradation and dissipation observed from burning of fossil fuels, which involve observable energy change in the form of light, heat, sound etc.
19. Students can observe and record the natural path of energy degradation and dissipation, like observing combustion of a fossil fuel and record, identify and discuss the energy changes, in ways that explain and is scientifically accurate.
20. Recording, comparing, discussing and questioning observed energy changes, in degradation and dissipation processes, can help identify patterns of behaviour, and help explain energy changes or draw further questions.
21. The law of conservation of energy is rarely applied to new contexts and only understood as a rote-learned definition.
22. Everyday use of the 'conservation of energy' concept contributes to the confusion of this energy concept, for example the inference associated with ideas connected to 'energy loss'.
23. Students experience difficulties in transferring energy concepts from different contexts e.g. the law of conservation of energy, from a physics context, to another science context, like biology or chemistry. Energy conversion in a battery, where chemical energy is changed into heat/light, is understood only as physics based and as energy conservation.
24. Energy comes from matter. Energy is an abstract concept, matter is concrete and observable. Energy and matter have the same law that governs their existence. The use of matter as a comparable conserved entity with energy, helps makes the concept of energy conservation more understandable.
25. Energy conservation is an abstract concept. Evidence for its existence can be seen in many physical events, like the steps of the water cycle or a balanced chemical reaction in open/closed systems, that can be modelled using coloured blocks, for example.
26. Exploring energy conservation in the context of matter, across the different science disciplines of biology, chemistry and physics, is useful in providing explanations, as well as more questions, help challenge beliefs about the concept of energy conservation.

Table 2 Pedagogical framework relating conceptual change to learning progression in energy concepts.

		Students' understanding of *energy concepts* across a progression sequence (Opitz et al 2017)			
		Energy forms/sources E1.	Energy transfer and transformation E2.	Energy degradation and dissipation E3.	Energy conservation E4.
C1.	1. There must be *dissatisfaction* with existing conceptions.	Students employ single objects to describe energy forms/sources and disregard a system-based approach, in many energy contexts e.g. wind energy. CUS 1 Visualising energy flow, forms and sources related to plants as primary producers of energy from the sun, where plants use sun, chlorophyll, water, carbon dioxide and nutrients, to manufacture glucose, a primary source of energy for living things, is challenging. CUS 2 Energy concepts involve micro-macro, atomic-molecular and quantum-mechanical perspectives e.g. the use of the ideal gas law PV=nRT to measure microscopic energy properties of a system, is a complex concept CUS 3	Heat and light is used to describe energy transfer in a chemistry context, whereas heat is seen as a by-product and indicator of inefficiency in a physics and biology context. CUS 9 Reactants and products in a chemical reaction are often confused as both the energy *and* the matter in a system. CUS 10 Energy transformation can involve complex chemical processes, e.g. in living organisms, plants use structures called chloroplasts and animals use mitochondria, as cellular energy factories, to handle energy transformation processes, to meet their energy needs. CUS 11	Students struggle with connecting events involving energy processes, where materials break down, recycle, as well as how they are formed, in both the natural and synthetic world. CUS 16 Entropy is a thermodynamic quantity representing the amount of energy in a system, that is no longer available for doing mechanical work. It is also a measure of the molecular disorder or randomness of a system. CUS 17	The law of conservation of energy is rarely applied to new contexts and only understood as a rote-learned definition. CUS 21 Everyday use of the 'conservation of energy' concept contributes to the confusion of this energy concept, for example the inference associated with ideas connected to 'energy loss'. CUS 22 Students experience difficulties in transferring energy concepts from different contexts e.g. the law of conservation of energy, from a physics context, to another science context, like biology or chemistry. Energy conversion in a battery, where chemical energy is changed into heat/light, is understood only as physics based and as energy conservation. CUS 23
Not Hierarchical C3.	2. The new conception must be *intelligible*.	Energy exists in many forms, as either potential or kinetic. Chemical energy is stored in bonds, in atoms or molecules. Bond formation results in more stable molecules, with lower energy. Elements bond together to give different molecules, and sources of energy e.g. hydrocarbons, like methane. CUS 4 Students must distinguish between energy forms and states of matter, where energy causes matter to change state, while energy comes from matter. CUS 5	Energy transfers through systems, in different forms, as seen in a food chain: *sun energy > chemical energy > heat energy etc.* CUS 12 Activation energy must be reached first, usually coming from an outside source, before a chemical reaction will start. CUS 13	Many practical examples of energy recycling exist in the natural world, e.g. the water cycle, the carbon and nitrogen cycles, as well as the degradation and dissipation observed from burning of fossil fuels, which involve observable energy change in the form of light, heat, sound etc. CUS 18	Energy comes from matter. Energy is an abstract concept, matter is concrete and observable. Energy and matter have the same law that governs their existence. The use of matter as a comparable conserved entity with energy, helps makes the concept of energy conservation more understandable. CUS 24
C4.	3. The new conception must be initially *plausible*.	Distinguishing between physical examples of energy forms and sources, is useful. For example; *forms*: light, heat, potential, kinetic *sources*: fossil fuels like methane gas, heating oil, coal. CUS 6 The chemical structure of sources can differ in bonding which can affect function and amount of activation energy required CUS 7	Understanding the concept of energy in different science contexts, like in biology, chemistry or physics, is useful and achievable through observing physical events representing energy transfer, like melting, evaporation, burning (combustion) and mass change in plants and animals involved in a food chain. CUS 14	Students can observe and record the natural path of energy degradation and dissipation, like observing combustion of a fossil fuel and record, identify and discuss the energy changes, in ways that explain and is scientifically accurate. CUS 19	Energy conservation is an abstract concept. Evidence for its existence can be seen in many physical events, like the steps of the water cycle or a balanced chemical reaction in open/closed systems, that can be modelled using coloured blocks, for example. CUS 25
Conditions needed for *Conceptual change* to happen (Posner et al 1982)	4. A new conception should be *fruitful*, suggesting the possibility of *deeper understanding*.	Classification of energy forms/sources as diverse, renewable or non-renewable matter is determined from measurement and extraction processes, application and uses of different energy forms, and factors that influence this. CUS 8	Measurable features of aspects of energy transfer can lead to understanding of processes involved, that give the changes observed, like melting, evaporating (state change) and burning (combustion), heat and light and contribute to understanding. CUS 15	Recording, comparing, discussing and questioning observed energy changes, in degradation and dissipation processes, can help identify patterns of behaviour, and help explain energy changes or draw further questions. CUS 20	Exploring energy conservation in the context of matter, across the different science disciplines of biology, chemistry and physics, is useful in providing explanations, as well as more questions, *help challenge beliefs about the concept of energy conservation.* CUS 26

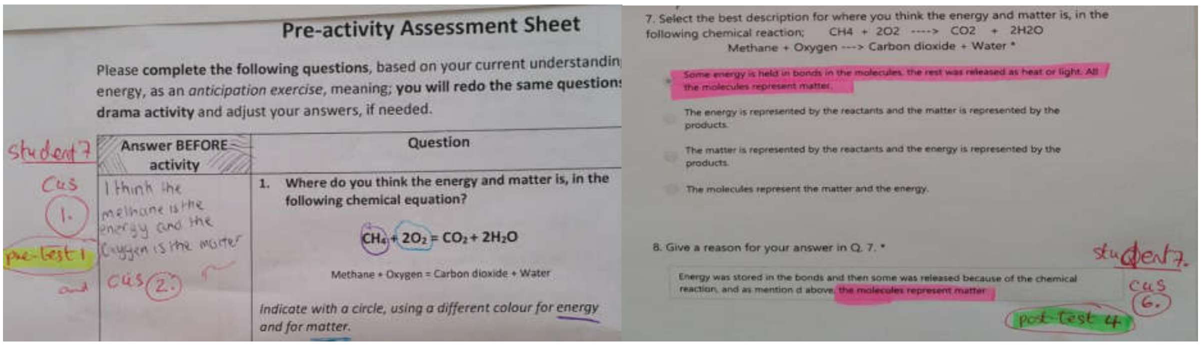

Figure 3: Sample coding of student responses - pre-test 1 (left) and post-test 4 (right) for student 7.

CONCLUSIONS

This study involved the development of a pedagogical framework to describe the relationship between Conceptual Understanding Statements (CUSs) and the conditions required for conceptual change and learning progression across Energy concepts. This framework was designed to evaluate if process drama can be used as a conceptual metaphor for teaching energy in the lower second level classroom. In particular, the approach adopted in this study involved students designing a dance, where they considered how to physical embody the concept of energy by becoming an atom in a molecule in a chemical reaction. The focus was to explore energy changes in a system and using relevant props, through the process of learning the steps of a dance, based on how the students predict the movement of the atoms in the molecules, achieve cognitive engagement. Many aspects of energy were explored in the designed activities, including the concepts of conservation of energy and matter.

Initial analysis of student responses from pre-test 1 and post-test 4 have begun to examine if the use of the pedagogical framework can lead to conceptual development. Initial coding of samples of student responses against 26 identified CUS's has revealed that conceptual change had occurred, e.g. changes from CUS 1 to CUS 6 after student 7 had completed the activity. There were many examples where the concept of 'the law of conservation of energy' understanding from a physics base, was over-used, to respond to biology questions on the student pre- and post-questionnaires and worksheets. Further analysis of all student responses is ongoing which will provide a holistic perspective on the effectiveness of the pedagogical framework developed as well identification of changes in student conceptual understanding that have been achieved through this approach.

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Supporting and enhancing the STEM and arts capacity of primary teachers and schools

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STEAM stands for Science, Technology, Engineering, Arts and Mathematics. STEAM Education Ltd provides a framework for industry and academic professionals to coteach science, technology, engineering, arts and mathematics with primary-school teachers through their STEAM-in-a-Box programmes. The professionals and teachers undergo induction in coteaching-pedagogy (Murphy, 2016), which aims at supporting them to share expertise in providing a stimulating, exciting, real-science learning experience for children. The programmes run for an hour per week over a period of between 10 and 25 weeks. STEAM-Education-Ltd (http://www.steam-ed.ie/about.html) comprises a unique partnership that unites actors from STEAM research, science education research, formal and informal science education, artists, designers and industry with one vision - to excite, inspire, and educate primary school children in STEAM through a direct connection with frontier research and development, via a partnership between industry, schools and academia. We provide resource materials, specially designed for primary class applications, and are developing Continuing Professional Development (CPD) in STEAM education. Our framework seeks to make a step change in STEAM education in Ireland through new investment and the leveraging of existing resources.

Keywords: STEAM education, Coteaching, Primary science, Industry-school-academic partnership.

INTRODUCTION

In Ireland, STEM (Science, Technology, Engineering and Mathematics) has been an area of increasing focus in recent years. In this project, we are directly addressing some of the proposed actions published in the recent STEM Review Group (2016) report, for example we:

- avail of partnerships with STEM enterprises to promote STEM careers at all levels in education.
- develop extensive curricular materials for teachers that operationalise learning outcomes in STEM subjects at primary/post-primary levels.
- promote and facilitate 'adoption' of a school, or cluster of schools, by a local STEM industry/enterprise.

The vision of STEAM Education Ltd. is to inspire young children to become the next generation of scientists, technologists, engineers, artists and mathematicians. We develop innovative, fun, engaging educational resources in these subject areas specifically for upper primary schools. We facilitate coteaching partnerships of science and arts industry professionals and academic experts with teachers to deliver these programmes, multiplying the benefits to all actors involved: the children, the teachers and the outreach experts. To date we have delivered programmes to approximately 5000 children in primary schools, with the support of over 30 companies, a number of Higher Education Institutes (UCC, TCD), a science foundation (www.thenaughtonfoundation.com), city and county council funding, and private donors. '*Science in a box'* (SIAB) was introduced initially in a small school in west Cork in

2006. It was the brainchild of a parent-scientist, who wanted to try out teaching 'rocket science' to children in 5th or 6^{th} class (circa 0 – 12 years old). Each week, the scientist arrived with a box of science materials, tailor-made for children to use and take home with them (including sheep's eyes!) or for them to use in the classroom and keep there. From this small beginning in one primary school class, STEAM Education has gone on to develop a number of programmes, and a framework for their delivery in schools around the country, supported by industry, academia and other sponsors. We see the development of this framework increasing engagement and input from and between various levels of the educational ecosystem and industry as leading to an "integrated educational ecosySTEM" (Figure 1).

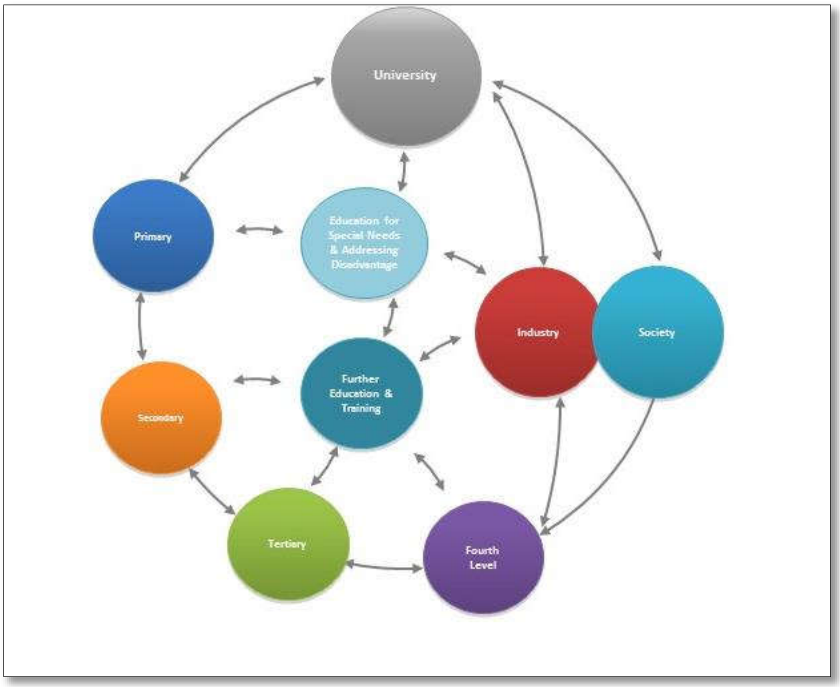

Figure 1: The STEAM integrated educational ecosySTEM framework

In addition, since our work entails coteaching between primary school teachers and STEAM experts, we are also enhancing primary teacher CPD in these areas. This relates to another issue identified in the STEM Review Group's (2016) report:

> An expansion of Science-based CPD and better use of CPD days would lead to improved science teaching in primary schools. Better use, and stakeholders, such as enterprise partners, will support CPD. (p. 33)

Research on coteaching science in primary schools shows that extraordinary results can be obtained through external specialists working closely with the normal classroom teacher (Murphy, 2016). Murphy's work also shows that coteaching via shared expertise provides a pedagogy which can be used to promote both teacher and student development of 21^{st} century learning skills, which include those of critical thinking and problem-solving, collaboration across networks, curiosity and imagination, empathy, persistence, grit and global stewardship. In addressing these needs, the SIAB programmes hope to provide a sustainable solution to these problems. Aspects of STEAM-in-a-Box have also been published in *Education Matters* (2017), *School Science Review* (2016), and in the *Trinity College Dublin Research Highlights* (2016).

The ultimate goal is to harness and share expertise via this public-private-industry collaboration to improve the STEAM learning of all students at every primary school; and thereby to increase the diversity in STEAM fields and the STEAM literacy of the Irish nation. The SIAB programmes also set out an ambitious programme of research through practice that will have high impact and will be transformative in science curriculum in Ireland, with further opportunities for a global impact.

THE DEVELOPMENT OF STEAM-IN-A-BOX PROGRAMMES

There are well-researched barriers to predominantly STEM focused approaches in education and despite significant national efforts to increase national STEM literacy, as recently as 2015 Science Foundation Ireland (SFI) reported that 71% of Irish adults feel Science and Technology are too specialised to understand. Meanwhile the STEM Review Group (2016) found that despite increases in scientific literacy in school students "*consistent findings across national and international tests of attainment (showed) that primary and post primary students find items assessing higher-order thinking skills (e.g. Applying knowledge and Problem Solving) particularly difficult*" (p. 20). Changing these perceptions and addressing these skills deficits are clearly critical to engaging in effective education.

Research also suggests improving the accessibility and inspiration levels in teaching; using content that is relevant to the lives of the learners; addressing negative gender stereotypes; and changing perceptions around subject difficulty and beyond-school opportunities will increase success of STEM interventions. Also notably a critical target age group for engagement was identified: children in primary school, ideally under 11 years old, before declining interest and motivation takes hold.

Taking these factors into consideration, in addition to the inclusion of arts (the A in STEAM) as a critical factor (Taylor, 2018), we develop all our programmes with a participatory, hands-on, cross-curricular approach. We endeavor to include not only an emphasis on scientific knowledge and understanding, but also an exploration of personal and cultural values, ethics, and citizenship. We believe that re-establishing the importance of arts and humanities as part of a more holistic system that addresses itself towards engaging the learner at a broader, deeper level, inspires both creative and critical thinking, as well as other 21st century learning skills.

In addition, the engagement of coteachers from industry and academia, to deliver the programmes with the primary teachers, bring both real life inspiration, and evidence, of relevant beyond-school opportunities that exist in STEAM subjects, and frequently, in the locality of the schools.

We currently offer three STEAM programmes to industry and upper primary schools: Science-in-a-Box, Engineering-in-a-Box and Maths-in-a-Box, with Technology-in-a-Box in development. To date just under 5000 children and 100 teachers in approximately 100 schools have benefitted from these programmes, supported by a philanthropic foundation, 30 STEM companies and 3 city/county councils.

COTEACHING STEAM IN PRIMARY SCHOOLS

The STEAM coteacher arrives at school once a week with a box of materials to facilitate engagement, supported with PowerPoint presentations and videos. For an hour every week for 10-25 weeks the coteachers engage the children in everything from environmental engineering to 'rocket science', depending on the specific programme. All programme content was designed to enhance the current primary school curriculum, while Science-in-a-Box complements and leads into the new Junior Cycle science programme. It similarly addresses nature of science as an overarching strand, and moves through the physical, chemical, earth and space and biological strands, using the 'big history' of the universe as both a means of structuring the course and as a narrative device. Children receive a STEAM journal at the beginning of each programme and are encouraged to follow up questions that arise in the classroom at home, do their own research and attempt to find the answers themselves. Bringing STEAM home with them is one way of extending their development by encouraging reflection on their learning, collaboration with friends and family and linking STEAM between home and school. The focus is on children's experience, and informal assessment is via quizzes and games.

Sharing of ideas, experience and expertise lies at the root of coteaching, as STEAM professionals and primary school teachers work together towards coplanning, copractice and coevaluating for the duration of the programme. Coteaching develops both coteachers' confidence as they share expertise and co-reflect on their progress towards providing 'ideal' learning environments for children. George Bernard Shaw's words illustrate the difference between sharing resources and sharing ideas, or expertise.

> *If you have an apple and I have an apple and we exchange these apples then you and I will still each have one apple. But if you have an idea and I have an idea and we exchange these ideas, then each of us will have two ideas* (George Bernard Shaw).

Coteaching comprises three interdependent phases: coplanning, copractice and coreflection.

- Coplanning is an essential aspect of coteaching. It provides opportunities for joint responsibility for the lesson and facilitates coteachers in clarifying their individual roles in relation to the particular lesson. Coplanning aims at coteachers planning 'ideal' STEAM lessons for the children, using a focus on enhancing learning for all instead of simply planning use of resources.
- Copractice describes the coteachers' roles in the classroom. During the lesson, it would be rare for both coteachers to be 'on the stage' throughout. More commonly, they move between roles during the lesson, depending on the activity. When copractice is fully attained, the practice of teaching is mutual and coteachers are able to anticipate each other's moves.
- Coreflection is required to guide coplanning for the next session using lessons learned. Coteachers seek tools to improve their lessons (perhaps advice from colleagues, books, online references, etc) and model solutions to episodes in the lesson that were not as successful as they had hoped.

It is when coteachers are copractising in the classroom that we get the best illustration of how coteaching works. During a single lesson, there are many ways that coteachers work together (see Figure 2).

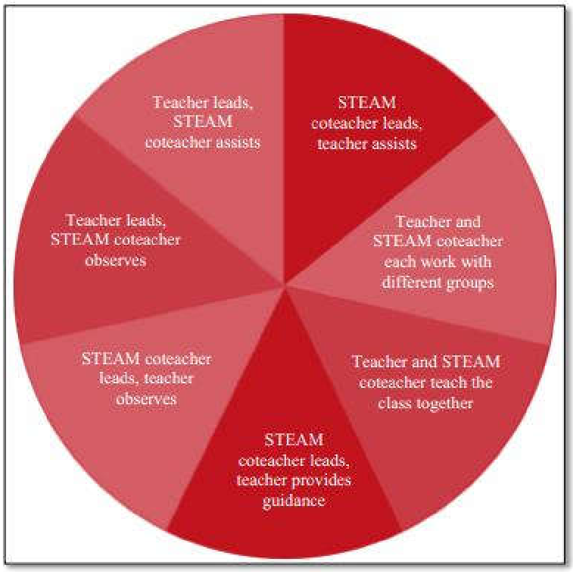

Figure 2: Some different forms of coteaching during a STEAM lesson

NEXT STEPS

Evaluation of the impact of our programmes is our next focus, so that we can capture the elements of STEAM-in-a-Box which are most effective in inspiring children in STEAM areas (Murphy, Mullaghy, D'Arcy, 2016), and introducing them to the place of STEAM in society. To date there have been two Masters' theses which have evaluated the early years of STEAM-in-a-Box. Both found that the programme thus far is successful in terms of child and teacher positive attitudes towards the lessons and highlight the importance of the coteaching element (Roycroft, 2015; Heffernan, 2016). Similarly, a review of SIAB currently being carried out on feedback from 27 classes in Leinster over 3 years found that majority of respondents agreed that SIAB has had a positive impact on both the science teaching and the attitudes of the children, to science, while all expressed a desire to have SIAB run in their school/class again next year. With regard to coteaching the majority of schools agreed that coteaching had beneficial effects for both children and teachers. Not all coteaching pairs work as successfully as others, however preliminary suggest that even the less effective coteaching teams see better coteaching as key to enhancing the success of the programmes and welcome the input and engagement of external content experts to the teaching of science in the curriculum. The full results of this study will be published in the coming months. Building on this 3-year review, and in advance of the next school year, we hope to develop both a pre and post evaluation framework to ensure that we are delivering effective, measurable change and inspirational programmes as we expand into new school programmes, including creative technology, health and well-being and climate change.

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Factors facilitating belief change for out-of-field mathematics teachers during action research

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Research on mathematics teachers' beliefs evokes a multifaceted link between a teacher's beliefs and his/her practices in the classroom. This is compounded for teachers of mathematics who are out-of-field (OOF) given that their beliefs may be shaped by their experiences in the classroom. A Professional Diploma in Mathematics for Teaching (PDMT) was designed and implemented from 2012, to address the issue of OOF mathematics teaching in Ireland. As part of this two-year, part time PDMT, teachers are required to complete an action research project. Examining one's own practices is the core form of action research utilized in the PDMT (McNiff & Whitehead, 2006). In this study, we employ Valsiner's zone theory adapted from Goos (2013), as a framework for conceptualizing OOF teachers' changing beliefs and practices during their action research. Valsiner's Zone of Proximal Development (ZPD), Zone of Free Movement (ZFM) and Zone of Promoted Action (ZPA) provides a means for theorizing teachers' learning in their individual context. Teachers' (n=576) action research papers were analyzed for evidence of reported beliefs and practices that relate to direct transmission and/or constructivism. The findings indicate the presence of both belief categories, with the action research project enabling a transition from direct transmission to constructivism through facilitating the opportunity for productive tensions to be created by OOF teachers, reconciling the ZFM/ZPA complex and enhancing teachers' development.

Keywords: Out-of-field teaching, Mathematics teaching, Beliefs, Practices, Action Research.

INTRODUCTION

It has long been recognized by education researchers that teachers' beliefs and practices are inextricably linked (Ernest, 1989; De Vries, Van De Grift & Jansen, 2014). The relationship between teachers' beliefs and their practices is interactive and subject to change. The complexity of the teaching beliefs and practices relationship is intensified when teachers are teaching out-of-field (OOF). OOF teachers are generally defined as those who are qualified teachers but are assigned to teach a subject(s) that is not consistent with their training and/or qualification (Ingersoll, 2002). Research relating to OOF teachers has highlighted the importance of exploring their lived experiences in order to understand the complexities that they face in teaching such a subject as mathematics when OOF (Du Plessis, Gillies & Carroll, 2015). In this paper, the authors analyze changes in OOF mathematics teachers' beliefs and practices on completion of an action research project. We apply Valsiner's zone theory (1997) to the OOF teachers' development in order to conceptualize changes, or lack thereof to address our research question: What factors facilitate teachers' changing beliefs and practices during action research in a professional development context?

BACKGROUND

OOF mathematics teaching is a world-wide issue and one that needs to be addressed. Research in the Irish context (Ní Ríordáin & Hannigan, 2011) identified that 48% of teachers teaching mathematics at post-primary level were not specifically qualified to do so. The OOF mathematics teachers in this study were all participants of a Professional Diploma in Mathematics for Teaching (PDMT), a national accredited programme in Ireland established in 2012 to upskill OOF mathematics teachers. It is a 2-year, part-time programme comprising both mathematics content (60 ECTS credits) and pedagogy (15 ECTS credits) modules and is funded entirely by the Department of Education and Skills. Teachers completing the PDMT remain in their teaching positions and complete the programme via a blended learning approach consisting of online lectures and tutorials, face-to-face lectures and tutorials, five weekend workshops and a one-week Summer Institute after Year 1 of the programme. One aspect of the pedagogy is an action research module which consists of 120 hours of research/private study and requires teachers to undertake a research project examining their own practice in the mathematics classroom. This takes place during Year 2 of the programme. Examining one's own practices is the core form of action research utilized in the PDMT (McNiff & Whitehead, 2006).

LITERATURE

Fundamental to exploring OOF teachers' lived experiences is the idea that mathematics teacher development occurs when teachers are required to address 'hard' questions about their teaching and beliefs (Jaworski, 1998). We wanted to examine this within an OOF mathematics teacher education context in Ireland. According to De Vries et al. (2014, p.339) "teachers' beliefs about learning and teaching are propositions that a teacher holds to be true about teaching and learning, they develop during the many years teachers spend at school, first as students, then as student teachers and teachers, and over time and use, these beliefs then become robust". Two belief orientations frequently discussed in the literature on teachers' beliefs about teaching and learning are direct transmission beliefs (also referred to in the literature as teacher-centred or subject-matter oriented beliefs) and constructivist beliefs (also referred to as learning facilitation, learning-centred or student-oriented beliefs) (De Vries et al., 2014). Although the two belief orientations may appear contradictory, teachers can possess characteristics of both in their practices. Central to understanding the relationship between teachers' beliefs and practices is the teacher's context, which can determine which beliefs about teaching and learning are employed in practice (Beswick, 2004) and may also be one of the main reasons for inconsistencies between teachers' beliefs and practices. This has obvious connotations for teachers in the OOF context and the authors wanted to explore OOF teachers' beliefs and practices and any self-reported evidence of change in beliefs or practices as a result of their action research. In order to change teachers' practices in the classroom, teachers' beliefs (especially effectiveness and feasibility beliefs) play a key role in the likelihood of teachers adopting an alternative teaching approach (Aelterman, Vansteenkiste, Van Keer, & Haerens, 2016). Action research provides the OOF teachers in our study with the opportunity to apply a proposed practice in their own context, thus allowing them to perceive the effectiveness and feasibility of the practice in their own teaching.

FRAMEWORK

Due to the significance of context in understanding teachers' beliefs and practices, we draw on sociocultural theory to conceptualize the OOF teachers' development as it occurs within their social environment. The authors draw on the work of Goos (2013) in adapting the theory of Valsiner (1997) and Vygotsky (1978) to conceptualize zone theory from the perspective of teacher-as-learner. Zone theory stems from Vygotskian theory of child development in which he defined the Zone of Proximal Development (ZPD) as the distance between what a person can achieve alone and with the assistance of more capable peers. Valsiner further developed Vygotsky's theory in 1997 to include the Zone of Free Movement (what is perceived as permitted and accessible by an individual within their environment) and the Zone of Promoted Action (ZPA) (all actions promoted both within and outside the ZFM). In conceptualizing the development of OOF teachers', we evoke Goos' understanding to define the ZPD for OOF teachers as the possibilities for developing new knowledge, beliefs, goals and practices in their

OOF teaching generated by the teacher's interaction with their professional environment, colleagues and resources. The ZFM for OOF teachers is considered as the professional context that structures their OOF teaching, while the ZPA refers to the teaching approaches recommended for the OOF subject by teacher education courses, professional development programmes and colleagues. Essential in the negotiation of teacher change and zone theory is the ZFM/ZPA complex and the notion of *tensions* created when the teacher's ZPD is inhibited by or misaligns with the ZFM/ZPA complex (Goos, 2013). *Productive tensions* develop when the teacher becomes dissatisfied with the misalignment and seeks to alter their environment (ZFM) or pursues e.g. professional development opportunities (ZPA) that will realign the zones to enable the teacher's development (ZPD).

METHODOLOGY

The study presented in this research paper is qualitative in nature and is centered on document analysis of action research papers submitted by OOF mathematics teachers (n= 576) enrolled on the PDMT between 2012 and 2016. Ethical approval was granted for a large-scale research project underpinning the PDMT, of which examining the action research component was part of the overall project. Consent was gained from participants on commencement of their studies. In Year 2 of the programme, teachers were required to undertake a project in a chosen area of mathematics education and to submit an action research paper (approx. 6000 words) documenting their project and key learning throughout the process. As part of the assessment process, teachers were also required to submit a project proposal (September, 10%) and research methodology/ethics (January, 20%). The project proposal generally served as the introduction section of their final paper, thus allowing for the observation of the OOF teachers' initial rationale in choosing their topic. Three levels of support were available to the teachers in order to assist them in undertaking their action research projects. One full day of a Summer Institute was dedicated to introducing teachers to action research and supporting them in commencing their project; they were assigned a specific, university-based supervisor who provided them with guidance and support throughout the process; and online support was available through the PDMT programme website. Papers submitted by teachers in 2014, 2015 and 2016 are utilised for the purpose of document analysis for this research paper. Given that the research papers were submitted for the assessment of a module on an accredited programme, it is important to keep this purpose in mind when assessing and interpreting the documents (Bowen, 2009). Document analysis involves both content analysis and thematic analysis and there are a number of key steps involved (Bowen, 2009). The first step entails skimming; a surface level examination of all of the available documents, in this case 576 action research papers, to identify the contribution to the research question being explored. Following the skimming process, conducted by both authors, 81 papers were identified as suitable for further analysis. The authors acknowledge the exclusion of the remaining 495 papers as a limitation of our study, but the teachers' beliefs and practices were not explicit in their submissions and accordingly could not be analysed for the purpose of this research project. The second step in the document analysis employed content analysis in order to organise the data in terms of their contribution to the research question. Three papers demonstrated direct transmission beliefs and practices prior to and on completion of the action research, 7 papers demonstrated constructivist beliefs and practices prior to and on completion of the action research, and 71 papers indicated direct transmission beliefs and/or practices prior to undertaking the action research and constructivist beliefs and practices on completion. The final stage of analysis focused on identifying key categories in relation to changes in beliefs/practices (71 papers, coded DT-C) and no change (10 papers coded DT-DT and C-C), in line with the conceptual framework.

FINDINGS

In this paper, the authors present findings relating to the zonal theory concept of tensions and productive tensions, as the main differentiating factor between the change/no change papers.

Existing Tensions

A key finding from this study relates to 'existing tensions' between these OOF teachers' ZPD and the ZFM/ZPA. For the majority of change cases (DT-C), there was evidence of genuine tension within these teachers' own thinking, and their awareness of the need to adopt constructivist teaching and learning practices.

> Thirty years ago rote learning was the way every student was taught and I feel this worked then because curricula changed rarely and advances in technology and science were not as widespread as they are today. Our students however are training for jobs that don't yet exist and therefore need to be able to transfer their skills to these jobs. (DT-C-38)

OOF teachers in this study had become more acutely aware of the importance of real-life applications, contexts and problem-solving skills for mathematics learning and life-long learning as a result of recent curricular changes (DES, 2010) and realised that their own practices did not align with this. Many OOF teachers utilized their action research to gain competence (ZPD) in new teaching approaches recommended by the revised syllabus (ZPA) in order to adapt their teaching to their changing perceptions of students' learning needs (ZFM). Completing this action research project afforded the OOF teachers an opportunity (ZPA) to develop their confidence and competence (ZPD) in adapting their teaching to their students' needs (ZFM): "I hope that this project will provide an opportunity for me to overcome my apprehensions and increase my knowledge" (DT-C-58).

Not all DT-C teachers demonstrated this existing tension. For some, the reflective nature of action research in choosing a project led to an increased level of consciousness relating to their teaching beliefs and practices.

> As I am a Science teacher, I practice co-operative learning on a regular basis in various science classes. On reflection of my teaching, I could clearly see that this strategy does not prevail in my mathematics classroom, with the content being delivered in a more teacher-centred manner. (DT-C-22)

They realised that they were teaching in a teacher-centred manner, inconsistent with their more constructivist beliefs about teaching and learning they held (ZPD), and the OOF context appeared to be a strong factor in this inconsistency (ZFM): *"I think that I was afraid of the class getting out of control or getting caught out as maths is not my first subject"* (DT-C-09). This led to a dissatisfaction with the teaching practices creating a tension between the ZPD/ZFM/ZPA and the action research became an opportunity to realign their beliefs and practices.

On the other hand, in the no change cases (DT-DT), there was less evidence of an existing tension and teachers were less willing to change their practices from *"the old reliable methods that have been getting me results for years"* (DT-DT-03). Similarly, for teachers already reporting constructivist beliefs/practices, there was no evidence of tension as their beliefs and practices appeared to already align with promoted constructivist teaching of mathematics.

Productive Tensions

For the change papers, both in the case of existing tensions and tensions that emerged through reflection, the perceived effectiveness of the teaching approach employed in their action research led to productive tensions. The tensions became productive through a re-evaluation of their teaching context (ZFM) in terms of students' needs, e.g. *"It [AR] has highlighted the importance of adapting our styles to an ever changing student need."* (DT-C-62) and through becoming dissatisfied with their previous practices in light of the effectiveness of the new teaching practice. Improving knowledge and confidence in constructivist practices in their OOF teaching was also an important part of making the tensions productive: *"…as a result of my findings and also improved confidence due to my continual professional development I have now changed my approach to teaching algebra"* (DT-C-57).

For the OOF teachers who adhered to direct transmission beliefs and practices, two were unconvinced of the effectiveness of constructivist teaching approaches and remained satisfied with their beliefs and practices in their teaching context. The third DT-DT teacher, while impressed with the benefits of constructivist teaching approaches, was *"hesitant to engage in extra burdens unless it is explicitly stated within a syllabus"* (DT-DT-02). The teacher was unable to resolve the ZPA with their ZFM thus impeding the development of productive tensions. For the C-C cases, as the teachers were already convinced of the effectiveness of constructivist practices, there was no tension between the ZPD and ZFM/ZPA to be made productive.

DISCUSSION AND CONCLUSION

Preliminary findings indicate the importance of tensions, and particularly productive tensions, in leading to a change in OOF teachers' beliefs and practices during their action research. Similarly, the need for existing tensions in order for change to occur was also indicated by Goos and Geiger (2010). While not all tensions were pre-existent in this study, the reflective component of AR led other teachers to consciously consider their ZPD and to reflect on how their own context aligns with the promoted approaches in the field. Ernest (1989) highlighted the importance of reflection on beliefs and practices in order to reduce disparity between the two. Actively researching the promoted teaching approaches led teachers to productive tensions as they became dissatisfied with their current teaching approach, often leading to a change in the teachers' perceived ZFM. Teachers that adhered to direct transmission did not show evidence of the existing tension and tended to adapt the ZPA to their ZFM rather than vice versa. This research paper highlights the potential of action research in the professional development of OOF teachers in terms of supporting the development of their teaching and learning beliefs and practices, particularly in terms of creating productive tensions. Admittedly, the study is limited in the number of teachers who reported on their beliefs and practices suggesting the importance of encouraging teachers to actively reflect on their teaching for change to occur. Further research is required to fully understand the professional development benefits of action research in the OOF context, not only in the demesne of beliefs and practice, but also in terms of pedagogical knowledge, confidence and accordingly, the enhancement of teaching quality at post-primary level.

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Examining 50 years of upper second level physics science curriculum development in Ireland

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In 1962 the OECD established an *Educational Investment and Planning Programme* for its industrial member countries. Ireland was assigned to the 'Northern Group' which included Denmark, Norway and Sweden. Part of that programme was to encourage new approaches to the teaching of science as well as highlighting the interdependence of science education and the national economies which demanded that governments formulate science policies rather than regard science as a culture entity (OECDa, 1965). This study focuses on how Ireland and five other European OECD countries – Denmark, Finland, the Netherlands, Norway and Sweden- addressed the challenges of developing an upper secondary physics science curriculum during the period 1960s-2010s. These six countries share many similarities – moving from an agrarian based economy of the 1960s to a technological/industrial one of the 21st century, a relatively stable homogenous population and moving towards adopting a national policy of inclusive education. A decade-by-decade time-line approach is used to discuss how the upper secondary school physics curriculum evolved over the past fifty years.

Keywords: Curriculum, Physical Sciences, policy development.

INTRODUCTION AND CONTEXT

In September 1961, the Organisation for Economic Co-operation and Development (OECD) was established with the mission 'to promote policies that will improve economic and social well-being of people round the world'. In October of the same year the first OECD conference – *Education and Economic Growth* – was held in Washington, U.S.A. (Elvin, 1962). A more expansive view of education for economic growth evolved from that conference – addressing the purpose of education versus the needs of society, reviewing pedagogies to meet changing contexts, considering the quality of training (of teachers) and trainers and the importance and usefulness of educational statistics as planning tools. At this time, there was also an acknowledgment that governments needed to develop science policies rather than regard science as a culture entity (Anon, 1964, 1965; Barro, 2001; Blöndal et al., 2002; Gass et al., 1967; OECD, 1966; Papadopoulos, 1967; Svennilson, 1963).

In October 1965, the European Ministers of Education held their fifth OECD conference in Vienna. Resolution No.3 of that conference centered "on present problems in Upper secondary education" arising from an increase in the number of students continuing into upper second level education and consequently the need to expand the type and range of courses provided. Some of the key resolutions discussed were:

> *both the demand for increased educational opportunity and national manpower requirements; different ways of providing upper secondary education – either as a distinct division of education or within the continuous process of secondary education as a whole; the organization of studies - either in a comprehensive or in more diversified forms.* (Anon., 1966, p. 301)

The focus of this study is to examine how Ireland and five other European OECD countries – Denmark, Finland, the Netherlands, Norway and Sweden – addressed these resolutions within the context of developing policies and curriculum for physical sciences (which spans the disciplines of physics and chemistry) at upper second level over the fifty year period 1960s - 2010s.

IRELAND WITHIN A EUROPEAN CONTEXT

In *Targets for Education in Europe* (Svennilson, 1962) Ireland was included in 'the northern countries' of Denmark, Iceland, Norway, Sweden and the United Kingdom. With the exception of Iceland and the United Kingdom, there were many similarities between Ireland and these northern countries– their agrarian-based economies were on cusp of moving to a technological/industrial one and their populations were relatively stable and homogenous. All of these countries had a centralized second level education system with curricula and standards established by national education ministries. The influence of the Lutheran State Church on aspects of the Danish, Swedish and Norwegian education was similar to the influence of the Roman Catholic Church on the Irish education system. In addition, Sweden and Ireland were among the first cohort of countries to take part in the OECD's *Educational Investment and Planning Programme* (An Roinn Oideachas, 1966).

At the time, the education system of the Netherlands offered a different perspective on education with an emphasis on science for all students and the use of practical based projects (Kortland and Floyd, 2005; Vermeulen et al., 1997). While sharing many of the similarities, as listed above, with Nordic countries, the Dutch system shared other characteristics with Ireland. For example, both Ireland and the Netherlands both have a system with a mixture of private and public schools. In the 1960s and 1970s both of these countries sought to introduce a comprehensive style of education modelled on that of the Nordic countries but were unsuccessful (Amsing et al., 2013; Clarke, 2010; Fleming & Harford, 2014).

Until the break-up of the Soviet bloc in 1991 little was known about the education system in Finland, which for political reasons had maintained a neutral stance vis-à-vis western countries (Majander, 1994). Finland joined the European Union in 1995, and it soon became apparent that they had developed a unique education system. Finland scores and ranking was consistently higher that their European neighbours in the OECD's Programme of International Student Attainment (PISA) scores, as illustrated in Table 1.

TABLE 1: PISA performance for Denmark, Finland, Ireland, Netherlands, Norway and Sweden for years 2000-2015, data extracted from:www.oecd.org/pisa/data/.

	2000		2003		2006		2009		2012		2015	
	Rank	*Marks*	*Rank*	*Marks*	*Rank*	*Marks*	*Rank*	*Marks*	*Rank*	*Marks*	*Rank*	*Marks*
Denmark	22	481	31	475	25	496	19	499	27	498	21	502
Finland	**3**	**538**	**1**	**548**	**1**	**563**	**1**	**554**	**5**	**545**	**5**	**531**
Ireland	9	513	16	505	20	508	13	508	15	522	19	503
Netherlands	Too low participation for comparability		8	524	9	525	7	522	14	522	17	509
Norway	13	500	28	484	35	487	n/a		31	495	24	498
Sweden	10	512	15	506	22	503	21	498	n/a		28	493

UPPER SECOND LEVEL PROGRAMMES IN 1960S

Across the European countries of Denmark, Finland, Ireland, Netherlands, Norway and Sweden students having completed their lower second level education had to choose between

(i) an academic/general secondary education or (ii) a vocationally orientated education path to continue their education, as depicted in Table 2.The programmes in the upper secondary-general path provided access to a University education; while the upper secondary-vocational path provided access to vocational qualifications and to further education opportunities and excluded access to a University education. The programmes followed in the upper secondary-academic path and the upper secondary - vocational path were distinct and did not allow for transfer from one system to the other (Garrouste, 2010; UNESCO, 1961). Consequently, students had to decide on their future career options when they selected their upper second level path. Sweden was the exception to this system and adopted a comprehensive education system in 1962. Another exception was Ireland where the duration of the upper second level system was a two year programme, while in the other countries students completed a three years programme.

Table 2: Upper second level programmes across six countries in the 1960s, Adapted from (UNESCO, 1961).

	Upper Secondary – General/Academic			**Upper Secondary - Vocational**		
Country	**Year 1**	**Year 2**	**Year 3**	**Year 1**	**Year 2**	**Year 3**
Denmark	General Upper Secondary Education (STX)	Higher Preparatory Examination (HF)		Home Economics schools	Commercial schools	Technical schools
Finland	Upper Secondary General Education			Vocational Education and Training		
Ireland	Leaving Certificate (LC) Programme			Vocational education	Technical education	
The Netherlands	General Secondary Education			Secondary vocational training	Domestic Science and Technical training	Training as an infant school teacher
Norway	Upper Secondary schools			Vocational schools		
Sweden	**Gymnasiums Professional schools**					

PHYSICAL SCIENCES CURRICULA AT UPPER SECOND LEVEL IN 1960S

Table 3, page 34, lists the specialist subjects/programmes available within the upper secondary – academic path in the six countries. In Denmark, Finland, The Netherlands, Norway and Sweden students were required to select one of these specialist programmes as well as studying a number of core subjects. For example, a Danish student entering the upper secondary – general path could choose the (iii) Mathematics & Science programme along with the four core subjects of religious knowledge, Danish, French and History (UNESCO, 1961, p. 415). The choice of subjects for Irish students was restricted to studying a total of 6 subjects – two of which were mandatory – Irish and Mathematics and selecting an additional 4 subjects from a range of 23 subjects. The list of 23 subjects appeared rather generous but the reality choices were determined by the entry requirements of the Irish Universities (An Roinn Oideachais, 1968, 1961).

TABLE 3: List of Subjects/programme available at upper secondary level in the 1960s. Adapted from Garrouste, 2010; UNESCO-IBE, 1969.

Country	Subjects/programmes available – one to be selected
Denmark	(i) Classical studies, (ii) Modern Languages, (iii) **Mathematics & Sciences**
Finland	(i)_Finnish language & Literature, (ii) Foreign Languages, (iii) **Mathematics, Physics, Chemistry**, (iv) **Natural Science** & Geography
Ireland	Irish + Mathematics and 4 other subjects from list of 23**other sujects as supplied by Minister of Education – which included **Physics, Chemistry, Combination Physics-Chemistry, and General Science**.
Netherlands	(i) Classics to include Latin and/Greek, (ii) **Sciences**
Norway	**(i) Sciences,** (ii) Modern Languages, (iii) Latin and /Greek, (iv) **Natural Sciences,** (v) Norse
Sweden	(i) Classical studies, (ii) **General Science,** (iii) General Studies

** 23 subjects listed on the Leaving Certificate programme for 1968 were: English, Greek, Latin, French, German, Italian, Spanish, Hebrew, History, Geography, Applied Mathematics, Music, Physics, Chemistry, General Science, Botany, Physiology& Hygiene, Physics-Chemistry, Agriculture Science, Domestic Science, Commerce, Drawing, Art. (An Roinn Oideachais, 1968)

UPPER SECOND LEVEL PROGRAMMES IN 2010S

By 2010, compulsory education was required for all students up to the completion of lower second level education across Europe (Eurydice, 2013). Reform of the upper second level systems in many of countries resulted in increased access to third level education either via the upper secondary-general route or the upper secondary-vocational education (Eurydice, 2013) Both Norway and Sweden developed a comprehensive system with extensive programmes which addressed both academic and vocational aspects within one system.

Table 4: Upper second level programmes in 2010s. Adapted from (Eurydice, 2015)

<table>
<tr><th></th><th colspan="3">Upper Secondary – General/Academic</th><th colspan="3">Upper Secondary - Vocational</th></tr>
<tr><th></th><th>Year 1</th><th>Year 2</th><th>Year 3</th><th>Year 1</th><th>Year 2</th><th>Year 3</th></tr>
<tr><td>Denmark</td><td colspan="2">General Senior Secondary Education - STX, HF</td><td>Technical-HTX Administrative-HHX,</td><td colspan="3">Vocational Education-</td></tr>
<tr><td>Finland</td><td colspan="3">Upper Secondary Education-General</td><td colspan="3">Upper Secondary Education - Vocational</td></tr>
<tr><td>Ireland</td><td>Transition Year - Optional</td><td colspan="4">Leaving Certificate (LC) Programme; LC Vocational Programme (LCVP), LC Applied Programme (LCAP)</td><td></td></tr>
<tr><td>The Netherlands</td><td>Pre-university - VWO</td><td colspan="2">Senior General Secondary - HAVO</td><td colspan="3">Senior Secondary Vocational - MBO</td></tr>
<tr><td>Norway</td><td colspan="6">Upper Secondary Education - 12 national programmes - 3 general education and preparation of academic university; 9 vocational /professional focus</td></tr>
<tr><td>Sweden</td><td colspan="6">Senior Secondary Education = 18 national programmes- 6 preparation for higher education;12 combining vocational, general and academic subjects</td></tr>
</table>

Table 4 depicts the increased number of programmes now available in the upper secondary-general pathway. For example, in Denmark four programmes –General Senior Secondary Education (STX), Higher Commercial Examination (HHX), Higher Technical Examination (HTX) and Higher Preparatory Examination (HF) were available. In Ireland, at upper second level, the Leaving Certificate (LC) Programme, the Leaving Certificate Vocational Programme (LCVP) and an additional programme – the Leaving Certificate Applied Programme (LCAP) (NCCA, 2002) were available. However, the LCAP programme did not provide direct access to universities or other third level institutions. In the Netherlands two programmes were offered, the pre-university VWO and the Senior General Secondary, HAVO, which were a continuation of similarly named programmes at lower second level. Students intending to study at university entered the VWO stream while students intending to pursue a higher professional education entered the HAVO stream (Ministerie van Onderwijs, 2016; Rijksoverheid, 2016).

PHYSICAL SCIENCES CURRICULA AT UPPER SECOND LEVEL IN 2010S

With the exception of Ireland, reforms and restructuring of the upper second level structures in Denmark, Finland, the Netherlands, Norway and Sweden lead to increased programme subject choices for students. Table 5, page 36, depicts the availability of physical sciences across the six counties in the 2010s. There was marked increase in the number of core subjects which included the physical sciences – except for in the programmes offered in Ireland and the Netherlands. In Ireland the LCVP module was available contingent to the subject choices made by the students (NCCA, 2015). In Finland, general upper secondary education comprised of two elements – compulsory courses and specializations/electives which related to the compulsory courses. For example, if physics formed part of the compulsory element then the specialization element also required selecting a number of the specialization courses in physics, i.e., Heat, Waves, Laws of Motion, Rotation & Gravitation, Electricity, Electromagnetism, Matter & Radiation. In Norway and Sweden, Natural Sciences/Science studies were included in the core subjects, irrespective of what electives were chosen.

DISCUSSION

This study was carried out against the background of *Resolution 3.d* of the Fifth Conference of European Ministers of Education in 1965 (Anon., 1966) with particular reference to the development of physical science curriculum in upper secondary education during period 1960s-2010s. In the 1960s there were two separate establishments providing second level education – secondary level education and vocational education were delivered by separate entities. A student entering secondary level education followed a distinct programme which was aimed at equipping students for accessing university. Those wishing to pursue a vocational programme/an apprenticeship joined the vocational school. Access to universities was possible solely through the successful completion of the upper secondary-general programme. This was the situation for Denmark, Finland, Ireland, the Netherlands and Norway. Sweden was the only country to introduce a comprehensive system in 1962 (Orring, 1965). The duration of the upper second level education was three years for Denmark, Finland, Netherlands, Norway and Sweden and two years for Ireland.

Fifty years later, in the 2010s, the duration of upper second level education was still three years. In Ireland the introduction of an optional first year – Transition Year (TY)- became the year one of a three year senior cycle acting as a bridge between lower second level and upper secondary (NCCA, 2014). However, it was optional for each school to decide whether or not to introduce such a transition year programme. The Leaving Certificate Programme still remained a two year programme as it was in 1960s. In Denmark, Finland and the Netherlands both the upper secondary - general and upper secondary-vocational, now provided access to all third level institutions and universities. Norwegian reforms of upper secondary education aimed to '*make it possible for all students to attain a recognised qualification, vocational*

and/or academic' (UNESCO-IBE, 2012). This reform was reflected in the twelve national programmes available in Norway as shown in Table 5. The Swedish Education Act of 2010 aimed to provide '*a good foundation for work and future studies and also from personal development and active participation in the life of society'* (UNESCO-IBE, 2012) and this was similarly reflected in the eighteen national programmes shown for Sweden in Table 5.
As can be seen from Table 3 which lists the subjects/programme available at upper secondary level in the 1960s, five of the countries offer a single course specialising in physical sciences. In Ireland, the physical sciences subjects were among a list of 23 subjects for students to choose from. By the 2010s, the same five countries had expanded the range of opportunities to study the physical sciences – either as part of a core group and/or a specialism as illustrated in Table 5. However, in Ireland the physical sciences subjects were still among a longer list of 31 subjects from which students were to choose four.

TABLE 5: Programmes and subjects available within upper secondary level education in the 2010s

Country	Programme	Core/Obligatory	Elective
Denmark	**STX- Maths, Sciences,** Linguistics, Social sciences. **HXT**-technical and natural sciences **HHX** – emphasis on business economics.	**STX:** Danish, English, 2nd Foreign language, history, physical ed. Classical studies, **physics**, an artistic subject, maths, **a natural science subject,** social science + two of (biology, **chemistry,** and geography) **HTX:** Danish, Technical science, English, **physics, chemistry**, maths, biology, technology, biology, communications/IT, social science and history of technology. **HHX** – no science components	**STX:** Depending on choice of specialised study programme – 2 of the following electives: English, **a natural science subject**, social science, **astronomy.** **HTX:** depending on choice of specialised study programme – philosophy, technology, innovation, history of ideas, business economics, psychology, statistics, physical education
Finland	**General Upper secondary**	47- 51 compulsory courses – covering languages, maths, **environment & natural sciences,(physics, chemistry, biology, geography)** religion/ethics, philosophy, psychology, history, social studies, Arts, Physical Ed., Music, Visual Arts, Health Education, Educational and vocational guidance	28-24 – specialisation courses available – these are electives relating to compulsory courses of same subject i.e. within course of Environmental & natural science – for example: there are **7 specialisation courses in physics – (Heat, Waves, laws of Motion, Rotation & Gravitation, Electricity, Electromagnetism, Matter & Radiation),**
Ireland	**Leaving Certificate Programme**	Irish + 4 other subjects from list of 31 subjects	English, Latin French German, Italian, Spanish, Japanese, Arabic, Russian, History, Geography, Applied Maths. **Physics, Chemistry, Physics-Chemistry,** Agricultural Science, Biology, Agricultural Economics, Construction Studies, Accounting, Business, Economics, Technology, Religious Studies, Design & Communications, Art, Classical Studies, Home Economics S & S, Mathematics.
Netherlands	**VMO**-Pre-university Education **HAVO** – Senior General Secondary Education	**VMO**--.Latin & Ancient Greek; Dutch language & Literature; English language & Literature; Arithmetic, Civics, Cultural & Artistic education; Physical Education**.** **HAVO-** Dutch language & Literature; English language & Literature; Arithmetic, Civics, Cultural & Artistic education; Physical Education**.**	**VMO-** Culture & Society; Economics & Society; Nature & Health (Maths., Biology, **Chemistry**); Nature & technology(Maths., **Physics, Chemistry**) **HAVO-**Culture & Society; Economics & Society; Nature & Health (Maths., Biology, **Chemistry**); Nature & Technology(Maths., **Physics, Chemistry**)
Norway	**General Studies Programme**	Norwegian, Maths., **Natural Science**, English, Social science, Geography, History, Religion & Ethics, Physical Education	One of 4 specialising programmes- Languages, **Natural Sciences & Maths**., Social Science; Economics
Sweden	**Higher education preparatory programme**	English, History, Physical Ed. & Health, Maths., **Science Studies,** Religion, Social Studies, Swedish.	Business Management & Economics; Arts; Humanities; **Natural Sciences**; Social Science; Technology

Sources: Websites of the following ministries - DENMARK: Ministry of Science, Innovation & Education**; FINLAND:** Ministry of Education & Culture; **IRELAND:** Department of Education & Skills: **NETHERLANDS:** Ministry of Education, Culture & Science: **NORWAY:** Ministry of Higher Education & Science: **SWEDEN:** Ministry of Education & Research.

CONCLUSIONS

It is remarkable how little appears to have changed in the education system at upper second level in Ireland during the fifty years from the 1960s to the 2010s. In the 1960s, a single national terminal examination existed that students must take to complete the Leaving Certificate (LC) Programme. At this time, achievements in the LC examination provided students access to universities, some teacher training colleges and the civil service. In the 2010s, there was still only one national terminal examination – the Leaving Certificate – and achievements at this stage provided access to the full range of further and higher level education course as well as access to immediate employment. There was no longer two education systems - both the secondary and vocational systems of the 1960s had merged to become a single second level education system. Comparing the list of subjects available in 1960s to those available in 2010s it is notable that subjects which once were in the domain of the vocational section – for example, construction studies, engineering, technology - were now part of the mainstream Leaving Certificate programme.

There also has been little changes made to the physical sciences curricula over this fifty year period. The current physics syllabus was introduced in 1999, the chemistry syllabus was also introduced in 1999 with some adjustments in 2013 as result of health and safety concerns about some chemical substances which were used in chemistry experiments. However, there have been changes made to the structure of the Leaving Certificate examination papers of these subjects during the time period. Some of these changes have been made as a result of changes in universities' entry requirements, efforts to make physical sciences subjects more appealing to students or responding to changing pedagogical approaches. A detailed analysis of the examination papers for physical sciences may provide deeper insights into these changes and perhaps clarify the relative static nature of the Physical Science curricula in Ireland.

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Accrediting pre-service teachers' innovative practice in primary science within an ITE programme: Why and how?

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Various reports indicate that the profile of science and technology in primary schools has decreased in recent years. As with what is happening in the primary school curriculum, science can seem squeezed within an already crowded initial teacher education programme. Insufficient time and resources for developing pre-service teachers' confidence and competence in teaching primary science may significantly compromise the quality of science provision in our schools. This situation is exacerbated by the fact that often pre-service teachers have limited opportunities to teach, or even observe, science lessons during placement. This paper provides a rationale and a description of a degree enhancement accreditation scheme for primary science. Based on the Primary Science Teaching Trust's 'Teachers' College' model the accreditation requires student teachers to evidence their competence in teaching, disseminating and engaging with the policy and theory which underpin their practice. The students are provided with opportunities to fulfil the criteria by engaging in science through a number of curriculum development projects with partner schools, dissemination seminars and an annual student conference. The skills and experiences gained through the course of the accreditation are designed to develop student teachers' sense of efficacy and agency and provide opportunities for them to network with schools in their community. As well as going some way to enhancing the current quality of science education, the scheme aims to nurture the potential science leaders of the future.

Key Words: Primary science, pre-service teachers, leadership.

INTRODUCTION

This paper describes why and how pre-service teachers may be accredited for their innovative primary science practice as part of a degree enhancement programme. As initial teacher educators and Academic Collaborators for the Primary Science Teaching Trust (https://pstt.org.uk/), our research explores how the pedagogy adopted within initial teacher education can best support and create new and better practice in science education. This accreditation model, the *Stranmillis Student Teachers' College* mirrors the Trust's *Teachers' College* where outstanding primary science teachers serve as mentors and beacons for curriculum development in their particular region of the UK. In addition to adding considerable value to the pre-service teachers' degree programme, the accreditation scheme provides the opportunity to begin to nurture future subject leaders at an early stage in their career.

PRIMARY SCIENCE IN NORTHERN IRELAND

Concerns have been raised that Science and Technology has become less of a priority in schools in England, Wales and Scotland, with too little teaching time set aside for this area (CBI, 2015). The report (p.15) states that 'half of those surveyed said that science had become less of a priority at primary school over the last five years… science is being "squeezed out with numeracy and literacy pressures". In Northern Ireland the merging of Science and Technology with History and Geography under the Area of Learning called 'The World Around Us' has been reported (Johnson, 2013) to have reduced its profile in the primary school, with '90% of teachers spending less time teaching science than four years ago [prior to curricular reform], and over 50% saying it had decreased substantially, leading to a reduction in science content and topics being taught" (p.9). The Education and Training Inspectorate's survey (2015) of science and technology provision within the 'World Around Us' considered that Science and Technology was underdeveloped in 54% of schools sampled and that 'provision focussed on low-level factual learning within isolated topics and lacked purposeful investigative experiences for children' (p.37). The most alarming statistic was that 28% of teachers sampled in NI did not feel confident teaching Science and Technology (ETI, 2015), in contrast to only 5% for History and 4% for Geography. The report highlights the lack of professional development for teachers in science and technology and the focus on Numeracy and Literacy as contributing factors.

STUDENT TEACHERS' EXPERIENCE AND CONFIDENCE IN TEACHING SCIENCE

A recent survey (Lowry, 2017) of final year undergraduate student teachers within an ITE institution in Belfast found that they lack experience and confidence in teaching primary science. Of the 66 students surveyed 41% had taught less than 3 science lessons throughout the four years of their B.Ed degree and 11% of students had never taught any science. Direction from the host teacher and their own personal confidence featured highly among the factors which they felt restricted their teaching of science during school placement. The most frequently cited means by which their confidence could be increased was the opportunity to observe science lessons other than during placement (70%), the opportunity to teach science lessons other than during placement (55%), and having more time within the ITE programme for primary science (60%). There therefore seems to be an appetite amongst student teachers to experience primary science beyond the context of their annual school placement. In addition to overcoming the challenge of finding space for science in an already busy school day, opportunities to teach science beyond the often assessment-driven context of school placement may encourage students to take risks and opt for more pupil-centred hands-on activities.

If it is the case that there is a decline in the quantity and quality of science being taught in primary classrooms then this could have a disastrous impact on future generations of teachers, and ultimately children. Given that school placement is the cornerstone for ITE programmes and the fact that school-centred models for ITE continue to rise, if students' experience of science during placement is quite limited then their own current and future science practice may also lack quality. A possible cycle of decline could therefore result as shown in Figure 1. A similar 'Catch-22' scenario relating to science education in Australia has been described by Kenny (2010), where in-service teachers lacking in confidence are less likely to model best practice for observing pre-service teachers let alone encourage or support them to teach science during their placements. We feel that it is vitally important that ITE institutions strive to break this potentially reductive cycle by providing on-campus learning activities which support pre-service teachers through their early attempts at teaching primary science.

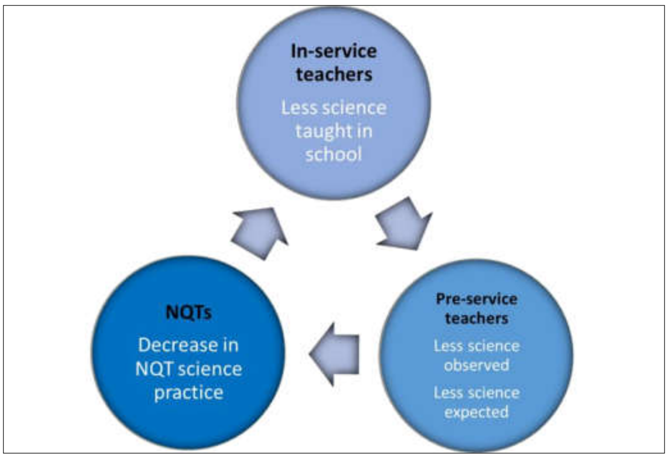

Figure 1: The potentially disastrous 'cycle of decline' for primary science.

THE ACCREDITATION SCHEME

To become an accredited member of the Stranmillis Student Teachers' College (SSTC), students are required to submit a portfolio of evidence which demonstrates their excellent classroom teaching and their involvement in professional development seminars either in a partner school with in-service teachers, or on the university college campus. The accreditation scheme is offered to all years of the B.Ed primary and post-primary programme and our PGCE course. In order to encourage as many students as possible to participate and to provide progression the accreditation is offered at two levels, Silver and Gold. For accreditation at Silver level a student's portfolio must evidence

- Excellent classroom teaching in teaching primary science
- Engagement in peer dissemination.

The dissemination of work to other students may take place within a science module or at a science sharing seminar in College.

For accreditation at Gold level students must meet the criteria for Silver and in addition provide evidence of

- Contributing to the development of science provision in a school through sharing their work with in-service teachers.
- Engagement with science education theory and policy through written assignments or critical evaluations of practice.

Therefore for Gold accreditation students must provide evidence of fulfilling the four criteria shown in Figure 2.

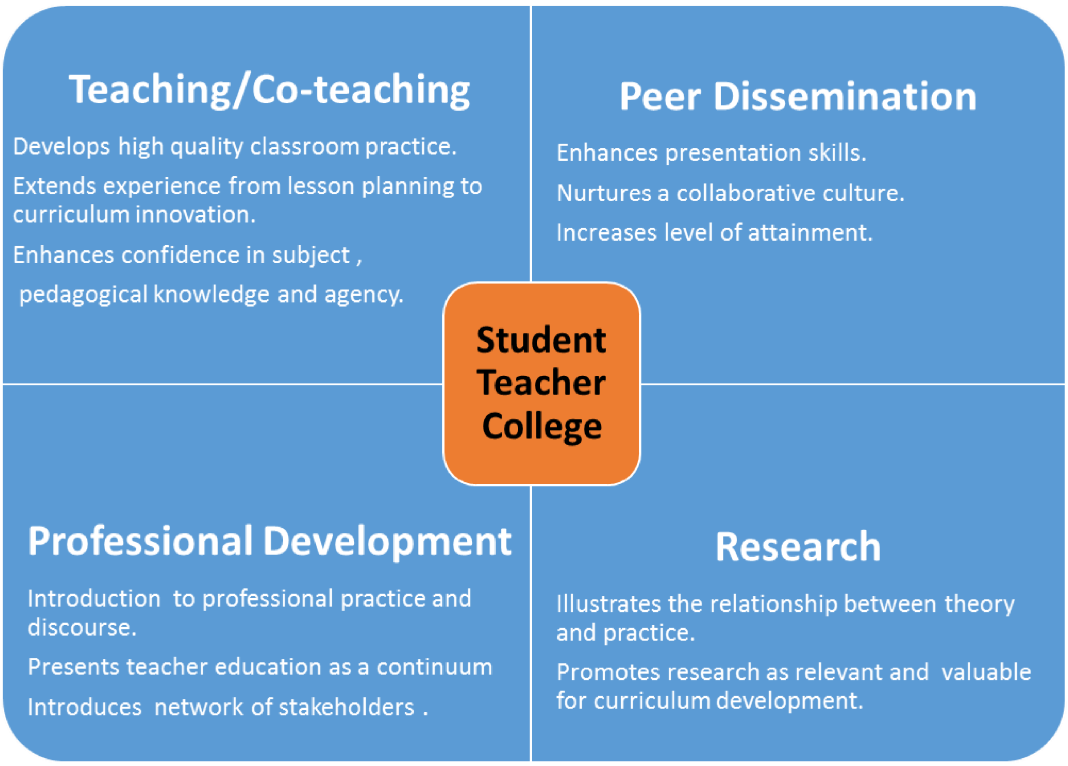

Figure 2: The four strands required for Gold accreditation.

STUDENT ACTIVITIES

At the beginning of term all students are invited to enrol for the accreditation programme. Students are encouraged to take every opportunity to teach science during day visits to their placement schools and to contact local schools and volunteer to work alongside a class teacher or science coordinator. Students can borrow resources and call in with science tutors for guidance or support. A list of activities is shown in Figure 3, along with how the activity could fulfil the accreditation criteria.

The principal event in the SSTC calendar is the annual conference. Students are invited to submit an abstract outlining a short presentation, a poster or a display of resources. All students, tutors and science education stakeholders and local teachers and science leaders are invited to the event. Students' abstracts, along with the programme, are posted on the College website so that students may evidence their participation within their curriculum vitae.

Activity	Accreditation Criteria
Teaching Science and Technology on placement	Excellence in Teaching Engagement with research
Curriculum development projects	Excellence in Teaching Engagement with research Peer Dissemination Professional development
Afterschool Science and STEM clubs	Excellence in Teaching Professional development
Student Conference and Project Dissemination Events	Peer Dissemination Engagement with research

Figure 3: Science activities and accreditation opportunities

NURTURING FUTURE SCIENCE LEADERS

We believe that the SSTC should serve as a community of practice for student teachers with respect to primary science and establish mind-sets and dispositions to professional development which hopefully will be sustained throughout their professional careers. The SSTC aims to nurture the skills and professional qualities of future subject leaders in science. Lawrence (2011) points out that new subject leaders may have had few opportunities during their initial teacher training or early professional career to observe and learn from good practice in primary science teaching and leadership and cautions that subject leadership training can be limited to generic courses which do not address the subject and pedagogical knowledge needed to support colleagues. The published vision for teacher professional development in Northern

Ireland, 'Learning Leaders: A strategy for professional development' (Department of Education, 2015), identifies 'building Leadership Capacity' (p.5) as one of its key areas and includes, as one of its 12 policy commitments, that 'leadership skills will form an integral part of all competence development from ITE and throughout a teacher's career.' Early career exposure to leadership can be advantageous. Being a subject leader requires a positive disposition to change and growth. Knight (2013) points out that from the very beginning of their teacher education courses students are more receptive and positively disposed to exploring the relationship between practice and theory than is generally believed. Initial teacher education should ensure that the future leaders of science education possess the necessary skills and competences to become critical and reflective exchangers of best practice and curriculum innovation. The programme should include opportunities for student teachers to develop an appreciation of the value of collaboration and ensure that they have sufficient confidence and sense of agency to inform their own and other's practice. All subject leaders should possess a deep belief that change is possible and a lived experience of having played an active role in bringing it about. This may be a big ask, especially during the early years of a teaching career, but to miss this opportunity during the formative years of a teacher's career makes little sense.

Acknowledgement: *The authors would like to acknowledge and thank the Primary Science Teaching Trust for funding and supporting this research.*

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Open schools for open societies: Encouraging innovation in schools and communities

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Citizens today are required to have a better understanding of science and technology in order to help them to participate in science informed decision making and knowledge based innovation (Hazelkorn et al., 2015). One way in which schools can help to address this challenge is through the concept of Open Schooling. An Open School is an engaging environment that makes a vital contribution to the community. The Open Schooling approach aims to move beyond the constraints of present structures through supporting teachers in designing and implementing an Open Schooling model. This model promotes and encourages collaboration with non-formal and informal education providers, enterprises and civil society to ensure relevant and meaningful engagement of all societal actors with science (Louisoni, Istance & Hutmacher, 2004). We are in the initial phase of introducing Open Schooling in Ireland in the context of the Horizon 2020 project Open Schools for Open Societies. We have conducted interviews with school principals in order to assess where they perceive their school stands in relation to the characteristics of open schooling. This paper presents a framework for the analysis of these interviews, along with the initial findings from two of these interviews. We discuss the findings in the context of the needs and expectations of schools as they move towards becoming Open Schooling hubs.

Keywords: Open schooling, School leadership, Responsible Research and Innovation.

INTRODUCTION

UNESCO's recent report "Rethinking Education: Towards a common global goal?" (UNESCO, 2015) reminds us that the changes that we face in the world today are characterised by new levels of complexity and contradiction. The changes we face also mean that citizens are required to have a better understanding of science and technology in order to help them to participate in scientifically informed decision making and knowledge based innovation (Louisoni, 2004). Encouraging innovation is one way that we can help schools and communities to face these complex changes and to encourage citizens to be more scientifically informed. Citizens of today are required to have a better understanding of science and technology in order to help them to participate in science informed decision making and knowledge based innovation (Hazelkorn et al., 2015). Education can equip learners with agency and a sense of purpose, and the competencies they need, to shape their own lives and contribute to the lives of others. The recently launched OECD Education 2030 project aims to build a common understanding of the knowledge, skills, attitudes and values necessary to shape the future towards 2030. (OECD, 2018). The aim of the project is to help countries find answers to two far-reaching questions: What knowledge, skills, attitudes and values will today's students need to thrive and shape their world? How can instructional systems develop these knowledge, skills, attitudes and values effectively? OECD Education 2030 project promotes the need for learner agency and building supportive relationships:

*Future-ready students need to exercise agency, in their own education and throughout life. Agency implies a sense of responsibility to participate in the world and, in so doing, to influence people, events and circumstances for the better. Agency requires the ability to frame a guiding purpose and identify actions to achieve a goal. To help enable agency, educators must not only recognise learners' individuality, but also acknowledge the wider set of relationships – with their teachers, peers, families and communities – that influence their learning. A concept underlying the learning framework is "co-agency" – the interactive, mutually supportive relationships that help learners to progress towards their valued goals. In this context, everyone should be considered a learner, not only students but also teachers, school managers, parents and communities. (*OECD, 2018).

One way in which schools can help to address this challenge is through the concept of Open Schooling. An Open School culture imports external ideas that challenge internal views and beliefs and, in turn, exports its students – and their assets – to the community it serves (Open Schools for Open Societies, 2017). Such an engaging environment makes a vital contribution to its community: student projects meet real needs in the community outside of school, they are presented publicly, and draw upon local expertise and experience. The school environment fosters learner independence – and interdependence – through collaboration, mentoring, and through providing opportunities for learners to understand and interrogate their place in the world. The principle of Open Schooling is interconnected with Responsible Research and Innovation (RRI) (Sutcliffe, 2006) which aims to develop strategies that link education content to wider societal goals and engage learners to become responsible citizens. Advances in research and innovation are crucial for overcoming the major challenges our society faces today such as the climate change, the aging population and mass immigration.

OPEN SCHOOLS FOR OPEN SOCIETIES

The concept of Open Schooling is being introduced to primary and secondary schools in Ireland though the Horizon 2020 funded project Open Schools for Open Societies (OSOS), 2017-2020. The aim of this project is to support 1000 schools, both primary and post-primary, adopting an Open Schooling framework in 12 different countries across Europe –including Bulgaria, Finland, France, Germany, Greece, Ireland, Israel, Italy, Netherlands Portugal and Spain.

The Open School Model provides school leaders with a powerful framework that can help them with transformation to an open school. This transformation can only take place if a school does not isolate itself, but opens up to other schools. Schools can form a hub together, in which schools help each other, collect good practices and share their experiences. Such an open and curious environment will support the development of innovative and creative educational activities. The model takes school settings into account and therefore ensures that school leaders can innovate in a way that is pleasant and suitable for schools. The model proposes a process and this process starts with the Change Agents who are becoming Inspiring Leaders of the school community. The OSOS support mechanism offers different solutions in the phases towards an open school. It supports school leaders to capture the needed steps for innovation, but it also supports them to decide a suitable strategy to spread the word throughout the school. Constant reflection is part of the process. The key objectives of the OSOS project are outlined in Table 1.

Promote the collaboration with non-formal and informal education providers, enterprises, parents and local communities	Through a focus on science learning at both primary and secondary levels, the framework proposes new and diverse models of collaboration between various stakeholders. The OSOS project aims to promote an approach based on collaborative learning and inquiry between professional practitioners. This collaborative learning takes place at all levels, from the classroom, through the school and within the community.
Support schools to become agents of community wellbeing	OSOS aims to support schools to develop project that solve the needs of real problems in the local community. By creating this model of collaboration with local stakeholders and by using activities that require the involvement of different actors, the participating schools will be linked with their local communities at a much deeper level.
Focus on effective parental engagement	Effective parental engagement in the projects will be encouraged. Schools are supported in this engagement and encouraged to utilise the expertise of parents.
Teach science for difference and address gender awareness	The Open School framework endeavours to respect students as individuals, and all of the activities associated with the project are designed so that students can share ideas, construct arguments, ask questions and analyse data in small groups. The activities and projects are based on educational approaches that produce the outcome of proportional participation of all genders.

Table 1: Key objectives of the Open Schools for Open Societies Project.

OPEN SCHOOLING IN IRELAND

In Ireland, ten schools were recruited during 2018 to participate in the pilot phase of the OSOS project and this included two primary and eight post-primary schools. An OSOS Champion teacher was identified to lead the implementation of an open schooling approach in their school. Over the past year, each school has been working with both the Irish OSOS project team and other community partners to create innovative science projects, called OSOS Accelerators, that are serving the needs of their local communities. One example of such an Accelerator is the "Greener Greens" project that highlights UNESCO's goal of *Responsible consumption and production of food (UNESCO, 2015).* This project has been developed by one of the Irish OSOS Champion teachers and he has implemented with first year second level students (aged 12-13 years). The focus of this project was to challenge student assumptions on the necessity of all-year round availability of non-seasonal fruit and vegetables. The teacher began a series of lessons by asking the students "Are the food choices we make sustainable?" The teacher asked the students if they were aware what fruit and vegetables were in season. The students knew that they could find most fruits and vegetables in their supermarket at any time of year, but was this the most 'natural' thing? Through reflecting on these questions, a number of investigations were designed by the students to challenge ethical and sustainability issues surrounding global food production and consumption, and possible resulting impacts on climate change and biodiversity. The students carried out their investigations using critical analyses of data and personal case studies. The students also involved the local community by engaging in discussions with local supermarket managers, with a view to encouraging them to provide more locally sourced produce. The projects were also taken home and students considered their own family's food choices. These investigations provided a rich basis for follow on classroom discussions on responsible consumption and production of food.

DETERMING THE IMPACT OF OPEN SCHOOLING

The OSOS project provides participating schools with numerous opportunities to engage in local, national and international activities with lasting benefits for school heads, students, teachers, the school and the local community. The Open Schooling Framework presents a range of outcomes that may be achieved by schools that engage in Open Schooling.

Professional development of school staff	Community building is considered a major professional development activity. As the project develops, more and more teachers and school leaders are expected to become involved and contribute to the development of projects and the shared vision of openness.
Connecting schools with stakeholder organisations, policymakers and the community	OSOS provides the means to extend learning and teaching beyond the school environment. School leaders, staff members and students can benefit through participation in activities that enable them to engage with local businesses, research centres, policymakers and community members.
Expanding pupils' horizons and raise their aspirations	The activities in OSOS can enable staff and students to work with partner schools both in Ireland and in several countries across Europe. This provides the opportunity to learn from the experiences of other students and teachers, and look at how projects develop in different cultures and contexts.
Improving teaching and learning	Through the project, schools have numerous tools available to assess their innovative practices and provide valuable feedback on students' performance while they work through Open Schooling projects. The OSOS activities allow teachers to foster project based and interdisciplinary learning and allow students and teachers to reflect on their learning and teaching together.
Raising the school's profile	The OSOS project recognises the unique achievement of the participating schools through the establishment of a core network of high performing school communities known as Open School Hubs. These Hubs are places where schools that are new to the project can find out more about Open Schooling, and will act as reference points for all participating schools. Participating in OSOS will also showcase schools at local, national and European Level.
Developing sustainable partnerships with community partners	Many schools have collaborations with community partners that have been developed on an ad-hoc basis. OSOS aims to support the development of sustainable partnerships with a wide-range of community stakeholders.

Table 2: Framework for Open Schooling.

A list of 40 indicators has been proposed by OSOS to collect evidence of impact of this project and measuring changes in Open School Principles I. Rethinking how schools work and II. Shift from students as consumers to creators, as presented in Appendix A. The OSOS project has developed a range of qualitative and quantitative instruments to collect evidence on these indicators with the key stakeholders, which includes School Principals, Teachers, Students and Community partners. A detailed plan of data collection points has been devised over the three year life time of the project in order to collect evidence (or lack of) for each OSOS indicator over a three year period.

The first questionnaire that School Principals are asked to complete is the School Development Plan (SDP). The SDP is completed by prior to the school's commencement in any OSOS activities and consists of a number of sections. Section 1 gathers school details and demographics and is mainly closed response. Section 2 examines *Where are we now?* and consists of 4 open response questions providing a "snapshot" of current practice in relation to open schooling. (i) Where do you think you school stands regarding the following opens school characteristics? (ii) What is the status of teachers as professionals, professional development and collaboration? (iii) Does the concept of open school resonate in school practices? (iv) Does the national educational system and its regulations allow autonomy to your school to develop as a learning organization? Section 3 probes the vision for the school, *Where do we want to go?* and consists of 11 open response questions providing an indication of each school's expectations of open schooling. Detailed analysis of each school's responses to these questions will be carried out using Qualitative Content Analysis (QCA) in order to determine what is the participants' initial conception of open schooling as described by the 40 OSOS indicators.

INITIAL FINDINGS

The findings presented in this work have been determined from an initial coding analysis of responses to SDPs completed by ten Irish School Principals prior to commencement of any OSOS activities in their schools. In terms of Open School Principle I - Rethinking how schools work -strong evidence was collected of three open schooling practices:

- *The school supports the development of an interdisciplinary environment where students/teachers are encouraged try new ideas and approaches. (Indicator 8)*
- *Parents actively collaborate in projects organised by the school. (Indicators 9, 14)*
- *Students identify and align stakeholder needs with matters of local social and economic concern. (Indicator 22)*

In contrast little evidence was collected of any practices that promoted enterprise and social entrepreneurship (indicators 7, 10) or opportunities for sharing and reflection between teachers, students or community partners (indicators 13,16,17).

In terms of Open School Principle II - Shift from students as consumers to creators – the strongest evidence of openness and growth was collected for collaborative practices, such as:

- *Schools projects and activities are related to issues of national or local interest in connection with the grand challenges (Indicator 34)*
- *Schools show evidence of engaging in virtual and physical platforms to develop new innovative projects, share ideas, identify and collaborate with other schools to develop innovative projects aimed at addressing the grand societal challenges (Indicator 33)*
- *Schools share Open Schooling approaches with other schools and external agencies on regional and national levels (Indicator 35)*

Little evidence was collected that recognized the school as a site of shared science learning in the community (indicator 39) or school engagement with policy makers to inspire curriculum change (indicator 40).

CONCLUSIONS AND IMPLICATIONS

These initial findings highlight current strengths and weaknesses in Open Schooling practices that exist in Irish schools. In the next phase of the project, the partners will support the sharing of cases studies, between schools and between teachers, that demonstrates the impact that an Open Schooling approach is having in schools. This action will support school leaders and teachers to gain a better understanding of how to foster opportunities to support a more Open Schooling Approach in their own contexts. These case studies also serve to illustrate how small changes and actions made by school leaders can have large impacts.

Further analysis of responses to SDPs will be conducted with a larger cohort (target of 100) of Irish schools, to determine if the culture for Open Schooling varies across Irish schools depending on school type, level, location, leadership etc. In the next phase of evaluation, the project aims to support school leaders to reflect on their practice and level of openness and to identify the role that school leaders play in the promotion and enhancement of STEM Education in their schools. These need to be explored further to evaluate if the Open Schools for Open Societies framework meets its objective and can identify and promote innovation in schools and communities.

ACKNOWLEDGEMENTS

The OSOS project has received funding from the European Union´s Horizon 2020 Framework Programme for Research and Innovation under the grant agreement No.741572.

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APPENDIX A

INDICATORS OF OPENNESS AND GROWTH (OPEN SCHOOLS FOR OPEN SOCIETIES, 2017)

Evidence	Indicators
I. Rethinking how schools work	
1. Holistic school approach and vision	1. The school has a clear vision and strategy towards open schooling
	2. At least one appointed teacher with clearly defined actions to support the open schooling strategy
	3. Strategies to encourage Problem Solving, Team Work, Active Citizenship, Critical Thinking and Gender Equality exist
	4. Approaches aimed at replacing competitive type classroom environment with more collaborative working approaches (that also addresses gender equality and inclusion) exist
	5. Plans for professional development of teachers for School Staff to foster a change in behaviour, enabling teachers to adapt to the open schooling culture
	6. Strategies for teachers to participate in international mobility actions are in place
	7. A motivation mechanism is set-up for teachers/students undertaking innovative projects and social entrepreneurial behaviour. Brokers, central connectors, and energizers are getting in action.
	8. The school supports the development of an interdisciplinary environment where students/teachers are encouraged try new ideas and approaches
	9. Parental engagement is integrated into the school planning structure
2. Effective Introduction of RRI principles	10. School supports and introduces student-led social enterprise start-ups community-focused courses
	11. School has an ongoing system of teacher and student self-reflection, discussion and learning set-up
	12. Teachers/students engage in platforms for sharing best practice and lessons learned
	13. Schools set up a system to reflect, track and monitor how open school practices have shaped the school organisational culture
	14. Parents actively collaborate with the OSOS projects organised by the school
	15. There is a commitment to changing the school at all levels
	16. Students and teachers incorporate a process of ongoing learning and evaluation into lessons and projects
	17. Students and teachers receive feedback from community partners and adapt projects, where possible, based on this feedback

	18. Schools encourage and engage in reflection, discussion and debates on scientific and societal issues
	19. All actors mutually benefit from the engagement in the projects and incorporate learnings into their systems and processes i.e. Industry update their CSR/business strategy, there is an economic cost-benefit
	20. There is evidence of an economic benefit-associated engagement of all partners
3. Effective and sustainable partnerships with external stakeholders	21. School has a system in place which captures the profiles, needs, contributions and relationships of all relevant external stakeholders
	22. Students identify and align stakeholder needs with matters of local social and economic concern
	23. School actively promotes the collaboration with non-formal and informal education providers, enterprises and civil society organisations
	24. School engages in a number of projects which demonstrate stakeholder inclusion
	25. School engages with outreach groups of research organisations to gain further insight into the life and careers of scientists/engineers (paying special attention into providing role models for all genders)
	26. There is evidence of parental engagement in school projects
	27. Schools increase the science capital of their communities
	28. Local/regional/national businesses and organisations share their infrastructures and collaborate or work within the school projects
	29. School works with research centres and science museums to develop initiatives using cocreative approaches, and vice versa
	30. Visits to research centres, science centres and museums are becoming the norm
	31. Formal procedures for stakeholder's involvement
	32. Participation and engagement of policy makers from key organisations in school projects and initiatives.
II. Shift from students as consumers to creators	
1. Educational resources generated in school settings according to local needs	33. Schools show evidence of engaging in virtual and physical platforms to develop new innovative projects, share ideas, identify and collaborate with other schools to develop innovative projects aimed at addressing the grand societal challenges
	34. Schools projects and activities are related to issues of national or local interest in connection with the grand challenges
	35. Schools share Open Schooling approaches with other schools and external agencies on regional and national levels
	36. Development of a support infrastructure for teachers and students to organise local conferences, workshops, cafes, exhibitions open days in the school with stakeholder involvement

2. Increased interest and motivation	37. Positive impact on learning outcomes – increased student motivation, increased interest in science, achievement of higher levels of problem solving competence and collaboration
3. Development of key skills	38. Positive impact on learning outcomes – achievement of higher levels of proficiency in problem solving and collaboration skills
4. Focused policy and support actions	39. The school is a recognised site of shared science learning in the community
	40. Schools engage with policy makers to inspire curriculum change

Conceptual change in upper second level electrostatics – The use of structured inquiry

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Many physicists, such as Faraday and Maxwell, developed the ideas that would become what is known as the field primacy theoretical framework (Pocovi & Finley, 2003). Students in upper second level physics education in Ireland are introduced to some of the ideas related to this framework when studying electric fields, and are required to represent them using both vector arrows and field lines (NCCA, 1999). However, it has been shown that numerous student difficulties are present in their understanding of the field model at both second level and third level (Galili, 1993; Törnkvist, et al., 1993; Cao & Brizuela, 2016).This paper presents findings from a case study completed with 14 upper second level students in Ireland, in which structured inquiry tutorials and multiple representations were used to help students develop their conceptual understanding of field lines. Pre-test and post-tests comparisons were used to identify student difficulties and to determine the extent to which conceptual change occurred (Hewson, 1992). Excerpts from the tutorial lessons are presented in this study to illustrate instances in which conceptual change was observed, based on the necessary conditions set out by Posner et al. (1982). Implications for teaching, focusing on the use of structured inquiry in the upper second level classroom are discussed.

Keywords: Electrostatics, Structured Inquiry, Multiple representations, Conceptual Change

INTRODUCTION

Upper secondary physics students in Ireland study many different topics in their physics course, such as optics, heat, waves, electricity, modern physics and particle physics (Physics Syllabus, 1999). This curriculum gives the students a wide foundational base, which can be used as a platform for further studies in Physics. However, many students struggle with aspects of the course, as detailed in the Chief Examiners' reports, published by the State Examinations Commission of Ireland. When considering the domain of static electricity, The Chief Examiner's Reports (2013; 2010; 2009; 2008; 2005a; 2005b) indicate that Irish students struggle with electrostatic concepts and that they tend to avoid questions relating to the topic. Their difficulties are in line with other international studies examining upper second level students (Galili, 1993; Törnkvist, et al., 1993; Arons, 1997; Marzec, 2012; Maloney et al., 2000; Cao & Brizuela, 2016).

Konicek-Moran and Keeley (2015) describe that conceptual understanding is observable when students can do things with their knowledge, such as think with a concept and use it in contexts different to that in which they learned it. Roth (1990) suggests that a conceptual change model of instruction is required to promote conceptual understanding. Hewson (1992) outlines there are three mechanisms for conceptual change: conceptual extinction, exchange and extension. However, learners' prior misconceptions can be difficult to overcome and Posner et al. (1982)

suggest that four conditions are required to enable conceptual change to occur: dissatisfaction, intelligibility, plausibility and fruitfulness.

METHODOLOGY

The case study in this research involved one cohort of upper secondary students (N=14). The cohort was mixed ability and mixed gender in a rural second level school in Ireland. The evidence gathered included data from pre-test/post-tests, student artefacts, teacher-student interviews, recordings of students' discussions and teacher reflections. This data was analysed and triangulated to collect evidence that conceptual change had occurred in the student's conceptual understanding of electric field lines. Tutorial lessons were designed and implemented in the format of *Tutorials in Introductory Physics* (McDermott et al., 2003). The emphasis of this approach was on student understanding of concepts and scientific reasoning skills, as opposed to rote learning theory or solving quantitative problems. This approach followed the pedagogical approach known as structured inquiry (Banchi & Bell, 2008), which has been shown to be an effective way to develop students' conceptual understanding (Tabak et al., 1995; Blanchard et al., 2010). The structured inquiry approach adopted was that the conclusion to the task was not pre-determined but based on the students' construction of knowledge through whatever activity was completed.

This study was carried out in a teaching-learning sequence over three stages (see Figure 1). In the first stage, the students developed understanding of vector concepts, the inverse square law, and field lines, in a mechanics context. In the second stage, the students transferred and applied their understanding of these concepts to Coulomb's law and the electric field, to develop their understanding in the context of electrostatics. In the final stage, the students applied their understanding of the concepts of vectors and field lines to develop their understanding of work and potential difference.

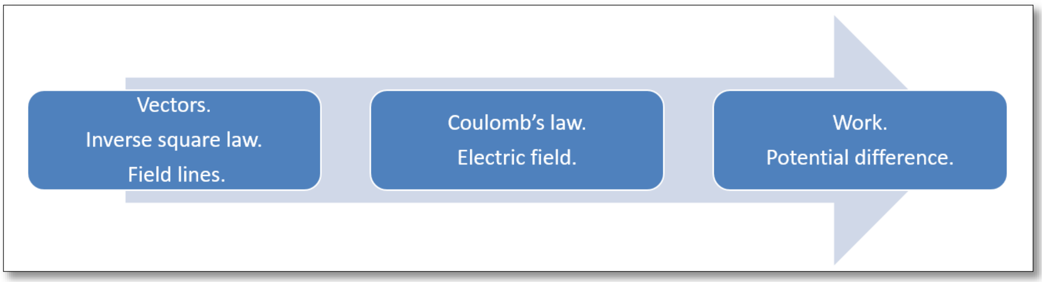

Figure 1: Teaching-learning sequence used to enhance conceptual understanding in electrostatics.

This paper will report on findings from the first stage of the teaching learning sequence and will address the following research question: To what extent does the use of a structured inquiry approach develop student understanding of the field line representation? The findings will focus particularly on students' understanding that field lines represent the direction of the force acting on a body, not the path taken by a body (Galili, 1993; Törnkvis et al., 1993).

RESULTS

In the pre-test survey, the students were asked to sketch the path taken by a body under the influence of the gravitational field of two nearby planets, as shown in Figure 2. The findings from the pre-test revealed that none of the students (N=14) interpreted the information represented by a field line pattern correctly. Five students appeared to think that the field line represents the path. One student indicated that the body would fall directly towards the leftmost planet, ignoring the effect of the gravitational field generated by the rightmost planet, and any force it may have experienced due to it. The remaining students did not formulate any reasoning to allow them to attempt this question. These interpretations and understandings have previously been identified in literature and are target concepts for conceptual change (Hewson, 1992).

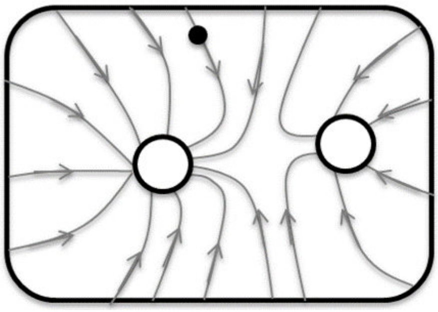

Figure 2: Pre-test question in which students were required to draw the path taken by a stationary body under the influence of the gravitational field of two nearby planets.

Prior to the tutorial lesson, the students were introduced to field line representations and the conventions associated with the representation in a lecture style presentation. During the tutorial lesson, the students were presented with a scenario in which a ball was thrown off a cliff; they were asked to analyse a strobe diagram of the event. Their analysis was guided so they would consider the velocity, acceleration and force acting on the body in turn. Students identified that both the acceleration and force acting on the body were constant. They then represented the gravitational field with lines. Three examples of student responses are shown in Figure 3. Whilst there are notable errors in some of the representations, such as field lines terminating in the air, field lines starting in the ball and field lines always passing through the ball, it is evident that students were starting to use the field line representation in a plausible and intelligible manner to build a model of the gravitational field in this scenario (Posner et al., 1982; Hewson, 1992). The difficulties observed were addressed in the second stage of this study.

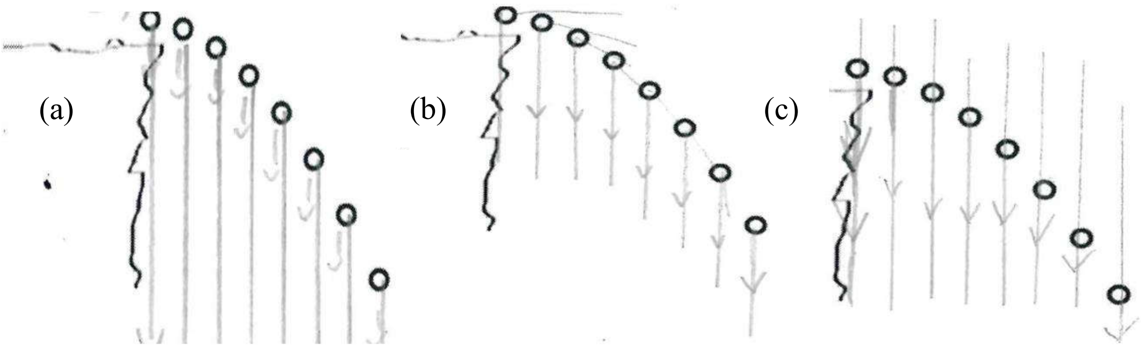

Figure 3: Samples of student responses (a) field lines begin in body, (b) field lines begin at the body and terminate, and (c) an accurate depiction of field lines.

The next section of the tutorial involved the students exploring a scenario in which a small meteor was moving with a linear velocity, v, and under the influence of the Earth's gravitational field, as shown in Figure 4. The students were required to analyse the variation of the field strength based on the field line density and sketch a reasonable path taken by the meteor. Students sketched different paths that the meteor would take with none of the student responses suggesting that meteor would follow a trajectory of one of the field lines in Figure 4. Some students depicted a minor deviation towards the planet, but mostly sketched a linear trajectory with no indication as to why the meteor would follow this path. We can interpret that the students reasoned (from their sketches) that the path of the meteor was effected by a gravitational force. However, students then ignored the gravitational force when they sketched that the meteor moved with a linear velocity after the deviation from its' initial trajectory, as illustrated with the trajectory shown by the red line in Figure 5.

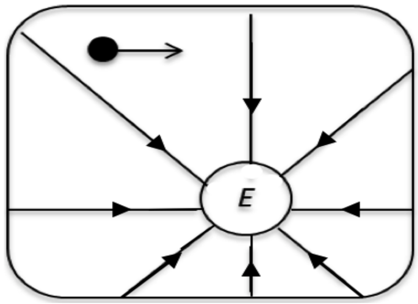

Figure 4: Diagram for difference between the direction of a field line and the path taken by a body.

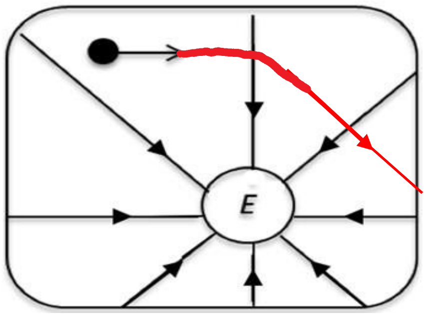

Figure 5: Illustration of incorrect meteor path drawn by students.

It is clear that most students consider the path trajectories only as a linear motion and it is important at this point to emphasise to the students why a circular or curved path might be considered. Although the most accurate paths to represent the motion would have been hyperbolic or elliptical, these types of paths would require a depth of understanding the students would not have developed at this point in their education of Leaving Certificate Physics or Leaving Certificate Applied Mathematics. Therefore, both a circular and curved path were considered valid responses. Each group was asked to explain their reasoning for their responses in detail. Three common themes emerged, with the number of participants for each presented:

- The meteor will try to move in the direction it is going with the initial velocity, but the gravitational attraction between the meteor and the earth will cause it to turn (n=11).
- This force will cause the meteor to deviate from its original path (n=14).
- The field lines will show the direction the meteor will attempt to turn instead of the path (n=11).

As the students used their conceptual understanding to construct reasonable paths, we observed that they were thinking with the concepts in a plausible, intelligible manner that was fruitful in an unseen context (Posner et al., 1982; Hewson, 1992). The students then revisited the initial question presented in the pre-test (Figure 2), and applied the same reasoning as seen in the previous question to that context. The students sketched paths the followed either of the trajectories seen in Figure 6.

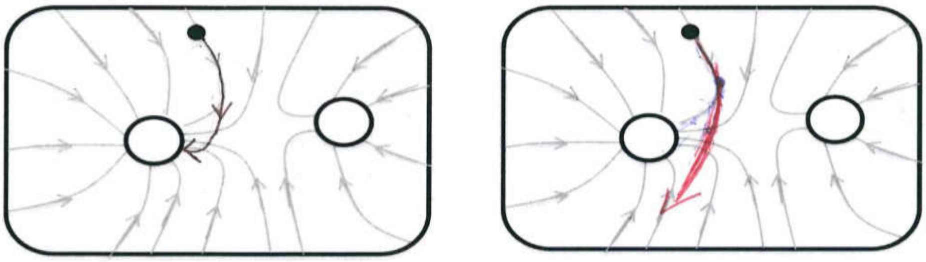

Figure 6: A sample of the two trajectory paths submitted by the students.

In the post-test, the students were presented with a "snapshot" of a field line diagram, with a small mass drawn as a black dot, (Figure 7). They were asked to sketch the path taken by the body, under the influence of the field. A summary of their responses is presented in Table 1. Most of the students explained that the meteor's trajectory would not follow the field line, as the body's inertia would prevent it from directly following the line. They explained that the body would move in the direction of the force acting upon on it and produce a path that is not represented by the pattern of the field lines in Figure 7. The students reasoned that the velocity of the meteor would carry it on a path that diverged from the sketched field lines. The response summary presented in Table 1 indicates that eleven of the students did not think of field lines as a path, and ten of these students could interpret the diagram sufficiently well to draw a path in which the trajectory was influenced by, but not identical to, the field lines shown. Thus most of the students advanced their conceptual understanding from the initial pre-test and produced reasonable paths with scientifically accurate reasoning (Posner et al., 1982; Hewson, 1992).

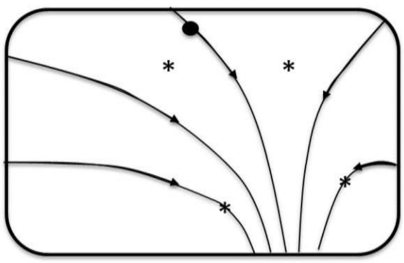

Figure 7: Post-test question field lines question.

Table 1: Students' post-test paths drawn taken by a body under the influence of a gravitational field.

Responses	**Frequency**
Path trajectory sketch diverges from field line pattern in a reasonable path	10
Path trajectory sketch diverges from field line pattern but is an unreasonable path.	1
Path taken follows the field line.	1
No path was determined.	1
N/A	1

DISCUSSION

In the pre-test, most of the students indicated that they thought the object would either follow the field lines or move directly towards the mass generating the gravitational field. Both difficulties were predicted from literature (Galili, 1993; Törnkvist et al., 1993) and these concepts were targeted for conceptual change (Hewson, 1982). The tutorial was written with three instances of a body moving with a trajectory influenced by a gravitational field. The students explicitly looked at this concept in two questions during the tutorial and referenced the first question during classroom discussions. As the students were familiar with the initial scenarios presented in the tutorial, they became dissatisfied with erroneous reasoning that failed to explain the observations accurately (Posner et al., 1982). The students were given ample opportunity to develop and apply the field line representation to explain the observations in the tutorial, and they used it to develop intelligible reasoning to predict the behaviour of objects under the influence of a field, both in contexts they were familiar with and in contexts unseen to them (Posner et al., 1982). In the post-test, all but two of the students correctly depicted a path that diverges from field lines. This shift in student responses from the pre-test to post-test indicates that the tutorial lesson was effective in promoting conceptual exchange in the students' understanding (Hewson, 1982).

CONCLUSION

The findings presented in this study illustrate how structured inquiry can be utilised to promote conceptual change in electrostatics, at upper secondary level. The student responses from pre-tests allowed the probing of their initial understanding and prior conceptions that were targeted for conceptual change. The analysis of tutorial lessons and student post-test responses allowed for the collection of evidence of conceptual change based on the conditions presented by Posner et al., (1982) and improved conceptual understanding (Konicek-Moran & Keeley, 2015). This study highlights how a structured inquiry approach enabled the majority of the students to demonstrate conceptual exchange in their understanding of electric field lines, and make visible their understanding throughout the teaching and learning sequence.

The tutorial lessons discussed were styled in the format of *Tutorials in Introductory Physics* (McDermott et al., 2003), which provided an appropriate strategy to achieve the goal of developing student conceptual understanding in Physics. A wider study on the use of this approach for other concepts in electrostatics at upper second level physics is presented in Moynihan (2018). This study further indicates that an inquiry pedagogical approach may be used in both a learning objective based syllabi or in a learning outcomes based specification for other domains of physics, such as optics, radiation, sound & mechanics.

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Developing pedagogical content knowledge in initial teacher education: Lesson study and peer assisted tutoring

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Learning to teach is a long-term and complex enterprise (Morris et al., 2009). In their commentary on initial teacher education (ITE), Hiebert, Morris, and Glass (2003) suggest that ITE programmes are more valuable when they support pre-service teachers to acquire the tools they will need to learn to teach, rather than focus on achieving complete and polished competencies of high-quality teaching. Peer-assisted tutoring and lesson study are two models which can build pre-service teachers' awareness of the knowledge and skills required to teach, while also providing them with tools to continue their path as life-long learners (Amador and Carter, 2018, Duah et al., 2014). In this paper, we will discuss the incorporation of these two models, conducted in tandem during one semester in the third year of a concurrent undergraduate ITE programme in Science and Mathematics. Seven pre-service teachers volunteered to participate in this research and qualitative data, generated through planning documents and weekly reflections, was analysed utilizing the Mathematical Knowledge for Teaching framework (Ball et al., 2008). Findings suggest that, due to their participation in peer-assisted tutoring and lesson study, these pre-service teachers developed important skills in noticing and reflecting as part of their repertoire of learning to learn to teach. Furthermore, findings suggest a development of their knowledge of content and teaching (KCT) and knowledge of content and students (KCS) over the course of the semester. This research may provide useful insight for ITE providers and teacher educators.

Keywords: Initial teacher education, Lesson study, Peer-assisted tutoring

INTRODUCTION

Initial teacher education (ITE) programmes strive to educate pre-service teachers to become high-quality, effective teachers. However, learning to learn to teach is a long and complex enterprise (Morris et al., 2009) and it may not be possible for ITE programmes to incorporate all of the learning required by pre-service teachers at the point of their graduation. Hiebert et al. (2003) suggest that rather than focusing on achieving complete and refined competencies of teaching at the end of ITE, programmes should instead focus on supporting pre-service teachers to acquire the skills and knowledge they will need to continue to learn to teach as life-long practitioners. Specifically focusing on the education of pre-service mathematics teachers, there have been calls to develop understandings of the knowledge and skills required to teach mathematics at post-primary level (Speer et al., 2015). Furthermore, research has suggested that ITE mathematics programmes should be developed to explicitly prepare pre-service teachers for the challenging and changing environment of teaching and learning (Hiebert et al., 2003).

This paper focuses on a recently established concurrent undergraduate to postgraduate post-primary Mathematics and Science ITE programme at University College Dublin. This programme, run through DN200 Science at undergraduate level and directed by the School of Mathematics and Statistics, has been designed to continuously develop both the content and pedagogical content knowledge of pre-service Mathematics and Science teachers over the course of their qualification. The programme incorporates four strands where students can qualify as Mathematics and one of Biology, Chemistry, Physics or Applied Mathematics teachers and is fully recognised by the Teaching Council.

In this research, we investigate two modules which are undertaken by all students within the third year of this programme. These modules separately incorporate a focus on lesson study (Lewis et al., 2009), where students participate in a full cycle over the course of one semester, and peer-assisted tutoring (or peer-assisted learning) (Duah et al., 2014), where students act as tutors to first-year undergraduate mathematics students for a semester. In this research we ask four questions, focusing on the initial two in this paper:

1. How is mathematical pedagogical content knowledge developed through pre-service post-primary teachers' participation in lesson study?
2. How is mathematical pedagogical content knowledge developed through pre-service teachers' participation in undergraduate peer-assisted tutoring?
3. How does participation in lesson study and peer-assisted tutoring effect pre-service teachers' self-efficacy in teaching mathematics?
4. How does this new knowledge of pedagogy manifest in their initial teaching practice?

This paper reports on initial analysis and preliminary findings of this research.

LITERATURE REVIEW

In their investigation of the knowledge required to teach mathematics, Ball and colleagues proposed a framework of Mathematical Knowledge for Teaching (MKT) (Ball et al., 2008). While this framework emphasises the importance of teachers' knowledge of mathematical content (subject matter knowledge), it also builds upon Shulman's (1986) definition of pedagogical content knowledge and incorporates the type of knowledge that is required uniquely of mathematics teachers (see Figure 1).

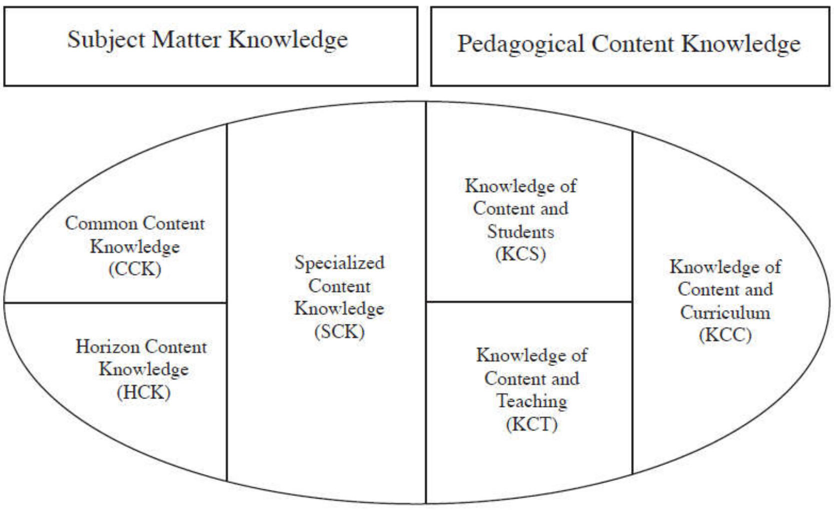

Figure 1: Mathematical Knowledge for Teaching Framework, Ball et al. (2008)

Ball et al.'s (2008) framework has become one of the most influential reconceptualization of teachers' knowledge (Depaepe et al., 2013). Research has demonstrated the importance of teachers' content knowledge and pedagogical content knowledge (PCK) in impacting their practice and impacting pupil learning (e.g., Baumert et al., 2010; Hill et al., 2008; Ma, 1999). Further studies have evidenced that high PCK cannot develop without strong content knowledge (Krauss et al., 2008). In reviewing models of professional development which support teacher learning, lesson study and peer assisted tutoring have emerged as ways of purposefully developing teachers' knowledge and skills.

Lesson Study

Lesson study, a model of teacher education originating in Japan, involves a collaborative group of teachers planning, conducting, reflecting on, and revising a research lesson in order to develop their understanding of mathematics teaching and learning (Fujii, 2018; Takahashi & McDougal, 2016). Much research has demonstrated teacher learning through lesson study (Ni Shuilleabhain, 2016) and also demonstrated positive impacts on student learning due to teachers' participation in the model (Lewis & Perry, 2017). More recently, lesson study has been incorporated in ITE and research has highlighted the skills and knowledge utilised and developed by pre-service teachers in their participation in lesson study (Amador & Carter, 2018; Corcoran, 2011; Leavy & Hourigan, 2016). However, few studies have yet focused on the development of pre-service teachers' PCK in post-primary ITE and none, as yet, in Ireland.

Peer Assisted Tutoring

Peer assisted tutoring (or peer assisted learning) is a model where students are assisted in their mathematics learning by peers that are close in age and educational level. Peer assisted tutoring has been shown to benefit undergraduate learning of mathematics (Duah et al., 2014) and research has demonstrated that undergraduate students can develop their pedagogical skills in noticing and communicating mathematical thinking by participating as tutors (Solomon et al., 2014).

ITE: Post-primary Mathematics

In this research, the directors of the ITE programme (authors of the paper) utilised the MKT framework to structure their design of content within the programme in an attempt to support the development of pre-service teachers' knowledge and skills. Considering the potential of lesson study and peer assisted tutoring to develop pre-service post-primary mathematics teachers' PCK, these models were incorporated into the programme. As part of their third year of undergraduate study, pre-service teachers complete a full cycle of lesson study, in groups of 3-5, as part of a core module. The research lesson is planned with the module lecturer (first author) acting as lesson study facilitator (Takahashi & McDougal, 2016). The research lesson is conducted in a nearby post-primary school and the pre-service teachers write a lesson reflection as part of their final report. In the same semester, these students act as peer-assisted tutors of a first-year undergraduate mathematics module within a core module of their ITE. As part of their learning, they reflect on their tutoring experiences through writing brief-but-vivid accounts (Mason, 2002) in order to develop their noticing skills of learners' mathematical thinking (Breen et al., 2014). In facilitation with the module lecturer (second author), pre-service teachers reflect on their learning from their weekly brief-but-vivid accounts.

METHODOLOGY AND PRELIMINARY FINDINGS

Seven pre-service teachers volunteered to participate in this research and data was generated through participants' weekly reflections, lesson study materials, and brief-but-vivid accounts. Analysis was undertaken according to a detailed framework of MKT sub-codes, as outlined by Ni Shuilleabhain and Clivaz (2017), and did not commence until all module grades had been assigned. Two samples of data from both modules are shared below and preliminary findings related to pre-service teachers' development of PCK are outlined.

Developing Knowledge for Content and Teaching

According to the MKT framework (Figure 1), Knowledge for Content and Teaching (KCT) combines knowing about teaching and knowing about mathematics (Ball et al. 2008, p. 401). This includes mathematical knowledge of the design of instruction such as: sequencing mathematical content, identifying or developing learning activities, and selecting models that support the development of mathematical understanding (Ball et al. 2008).

As part of their lesson study planning process, pre-service teachers developed tasks to match their articulated learning outcomes for the research lesson. One group of pre-service teachers designed a Geometry lesson and, at the beginning of the lesson, wished to revise pupils' knowledge of Trigonometry. The pre-service teachers designed a matching task which would encourage pupils, working in pairs, to articulate their understanding of right-angled triangles and Pythagoras' theorem, while also introducing pupils to the concept of inverse trigonometric functions (see Figure 2).

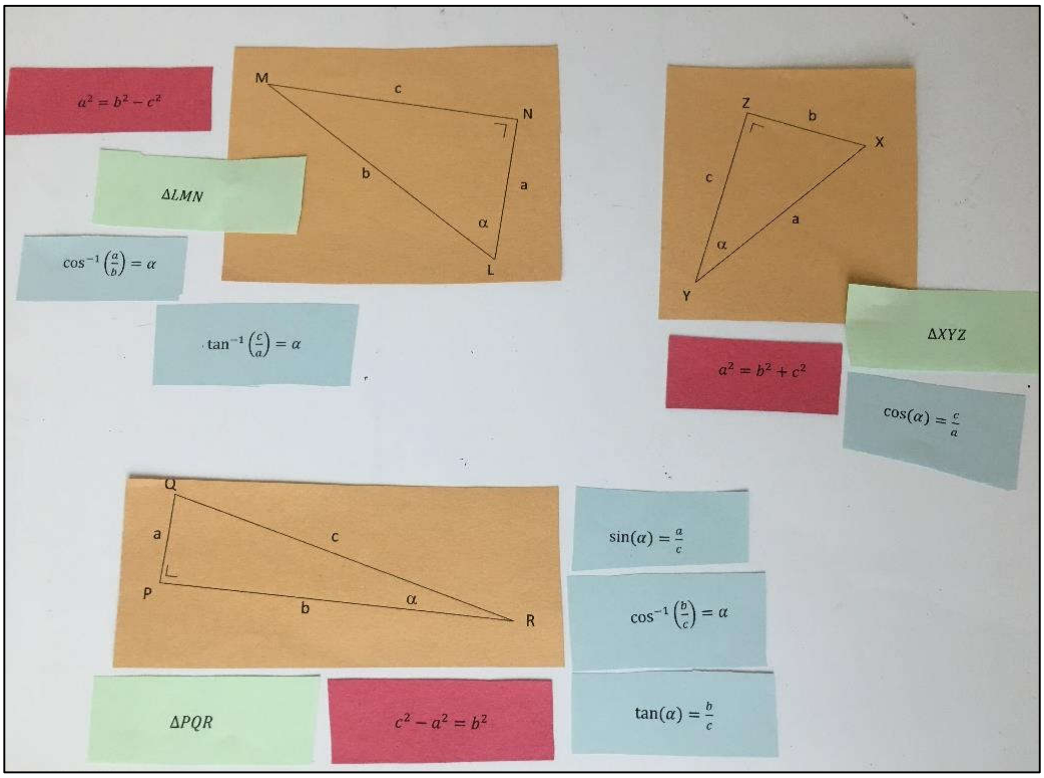

Figure 2: Mathematical task designed by pre-service teachers as part of their lesson study planning work

The creation of this task represents the development of these pre-service teachers' KCT, where they designed a learning activity and selected specific representations to support the development of pupils' understanding. Furthermore, in their lesson study reflection, these pre-service teachers recognised a need to further highlight the mathematical language they used during the lesson, distinguishing the angle 'alpha' from the side 'a'.

Developing Specialised Content Knowledge

Specialised Content Knowledge (SCK) represents a form of mathematical knowledge and skill that is unique to teaching. Types of SCK include: unpacking the mathematics of a pupil's work, looking for patterns in pupil errors, and explaining or justifying mathematical ideas (Ball et al., 2008). By participating in peer assisted tutoring, pre-service teachers were supported in developing their SCK by writing reflective, brief-but-vivid accounts of their interactions with learners. The following is a sample reflection from a pre-service teacher Emma (pseudonym) who had assisted an undergraduate student with a differentiation task.

Emma, Brief but Vivid Account "The Mysterious Three", Week 8

> *I asked a student who was sitting on their own if they were okay. They told me they didn't need any help. However, I glanced down at their page and saw that when they differentiated $f(x)=2ln(3x) - e^{x/2}$ they got:* $f'(x) = \frac{2}{3x} - \frac{e^{x/2}}{2}$.

I asked the student whether they had their notes on differentiating the natural log with them to which they replied "I know the rule - it is 1/x."

I questioned why they kept the 3 when differentiating 2ln(3x) and they told me that they didn't keep the 3. I paused and stared at their page. I pointed to the 3 in their answer and asked "So where does this come from?" The student explained that they divided everything by 3 first and they then scribbled the following on the page:

$$2\ln(3x) = (2/3)\ln(x)$$

I asked them why they divided by 3 and the student let out a sigh: "To get rid of the 3 in brackets". They paused before asking: "How else could I have differentiated it to get 1/x?"

By being attuned to the student's thinking, Emma realised that the learner was not making an expected common error of differentiation, but rather was demonstrating a misunderstanding of 'log' as a function. This represented a new student misconception for Emma and, by looking for such patterns in student errors, she developed her SCK.

DISCUSSION AND CONCLUSION

Teaching mathematics is complex work and in order to prepare pre-service teachers for their future careers, it is important to support them in learning how to learn to teach (Hiebert et al., 2003). In this paper, we have focused on an ITE programme which incorporates models of lesson study and peer-assisted tutoring as part of a concurrent undergraduate to postgraduate course. These models of teacher education are included in this programme in order to begin developing pre-service teachers' knowledge and skills and build their Mathematical Knowledge for Teaching (Ball et al., 2008).

In this paper, we have shared preliminary findings of research into developing pre-service teachers' PCK through lesson study and peer-assisted tutoring. Further analysis is required in order to fully explicate how PCK is developed through these modules. Additional research is also required on how such learning may impact pre-service teachers' classroom practices following their participation in these modules.

There are several limitations in this research since it involves a small number of pre-service teachers. However, we hope such research will contribute to the literature on ITE in mathematics and will be of interest to other ITE programme designers.

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Creating research-practice collaborations to address gender imbalance in physics at second level

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The numbers of students studying physics in upper second level and the low numbers of teachers completing a qualification to teach physics at second level is a matter of concern for STEM Education. This study will discuss the research-practice partnerships created between physics education researchers and seven second level schools in Ireland to address this challenge. The focus of these collaborations were to enhance teacher's approaches to the teaching and learning of physics at lower second level and to raise awareness about teachers' and students' unconscious biases and gender stereotyping. The formation of these research-practice partnerships to implement a three-strand approach to address gender imbalance in physics will be discussed.

Keywords: Inquiry, Gender, Professional development, research-practice partnerships

INTRODUCTION

There is a strong concern internationally about the impact of the under representation of women in Science, Technology, Engineering and Mathematics (STEM) and particularly in the discipline of physics (Hill et.al, 2010). Professional organisations, such as the Institute of Physics, have highlighted that the participation rate of females in physics remains stubbornly low with a ceiling of around 25% (Institute of Physics, 2016). According to a national survey carried out by iWish in 2017 which presented findings from the responses of 2,397 girls from across 15 counties, 82% wanted a career where they can help other people yet could not see how STEM can facilitate that (iWish, 2017). These findings highlight the gender gap which permeates the education system and is in itself a barrier to participation of young women.

In Ireland, typically only 13-14% of students choose to study physics at upper second level and complete the Leaving Certificate Physics Examination and of this cohort only 25-26% are girls. (State Examinations Commission, 2018). Worryingly, 22% of Irish second level schools do not offer Physics as a separate subject at upper second level. As highlighted in the 2016 report on STEM Education in the Irish Education System an imbalance in the numbers of teachers qualified to teach physics leads to the situation that the majority (greater than 80%) of second level students do not encounter a specialist physics teacher at lower second level which contributes to the lack of popularity of the subject at Leaving Certificate level (Education, 2016). In 2017, the registrations of the Teaching Council of Ireland indicated that 3878 teachers were registered to teach Biology, 2376 registered to teach Chemistry and 1259 were registered to teach Physics (STEM Education Review Group, 2016). All of these teachers are recognized to teach junior cycle science at lower second level (students aged 12-15 years) resulting in the majority of students never learning physics from a qualified physics teacher. Developing a strong physics content knowledge is essential to processing and understanding physics concepts and utilizing appropriate pedagogical approaches into classroom practice. Etkina (2010) highlights five aspects of CKT (content knowledge for teaching) that bridges the gap between content and pedagogy in the teaching of physics; orientation towards teaching, physics curriculum, student ideas, effective instructional strategies, assessment methods.

The situation in Ireland is not unique, with many countries seeking to address low numbers of teachers qualified to teach physics at second level. In England, physics teacher recruitment had hovered at about 400 each year from 1970 and reached an all-time low of 200 in 2001 (GOV.UK), while entries for physics A-level declined by 40 % in the 20 years to 2006 (Institute of Physics, 2006) However, following significant Government intervention, in partnership with the Institute of Physics, both trends have reversed in England with physics teacher recruitment figures reaching an all-time high of 920 in 2012 and an average annual recruitment over the past five years of 750.

In Ireland, with just over 13% of overall student cohort and 3.5% of overall female cohort participating in physics at upper second level, the need to concentrate on encouraging more students, particularly girls, to continue in physics is paramount. Ito (2018) writes that student perceptions of pSTEM fields (physical science, technology, engineering and mathematics) can strongly influence students' interest in these subjects. High school students in the USA who associated pSTEM subjects with an innate ability or requirement of brilliance showed lower tendencies to pursue these fields further, especially among females (Ito, 2018). Archer et.al (2010) also associates science identity with student identification of science and their perception of its [science's] usefulness in the future, while Lewis (2017) emphasizes the importance of focusing women's sense of belonging in pSTEM in order to increase persistence in these subjects. Strengthening the pipeline from early childhood to higher education leading to an increased uptake of STEM careers is of utmost importance to our global economy. However, the ASPIRES research reported that most young people and their parents had a very narrow view of where science careers can lead them (Archer et.al, 2013).

METHODOLOGY

The design of this study is based in the formation of research-practice collaborations with principals, teachers and students from seven second level schools in Ireland (Penuel, 2017). The participants consisted of 405 teaching staff, of which 51 were science teachers, with access to 5,149 students (3,078 girls, 2,071 boys) across the seven schools. The schools were selected to be representative of the wider cohort of Irish second level schools and includes two all-girls schools, and four co-education schools and are a mix of urban and rural locations. The 2018 statistics from the Deparment of Education show that of the 715 second level schools in Ireland, 67% are co-educational, 19% are all-girls and (482) and 14% (101) of schools are all-boys. In terms of the student population, of the 357,490 students attending second level education, the majority, 64% (228,753), of students attend co-ed schools with 41% (72,456) of girls attend all-girls schools, and 31% of boys attend all-boys schools (Department of Education, 2018).

The aims of this study were to address the uptake and gender imbalance in physics at senior cycle and adopted a three-strand approach to:

- enhance science teachers' approaches to the teaching and learning of physics in Junior Cycle science;
- increase the awareness of STEM and careers in STEM;
- adopt a whole school approach to addressing unconscious bias and gender stereotyping and build confidence and resilience for students, particularly girls, to continue with Physics.

Figure 1 presents an overview of the focus of the three strands (Physics Knowledge, Unconscious Bias and Career Awareness) along with the quantitative and qualitative methods being used to collect evidence of the impact of this three-strand approach. The first strand, physics knowledge, focused on the implementation of school-based workshops to improve physics Pedagogical Content Knowledge (PCK) of lower second level science teachers. These workshops also incorporated the strands of increasing awareness of unconscious biases and career awareness in STEM. To evaluate the impact of these workshops on teacher learning, the participating science teachers were asked to co-develop physics lessons, document their teaching and learning approaches and complete reflections on their classroom practices.

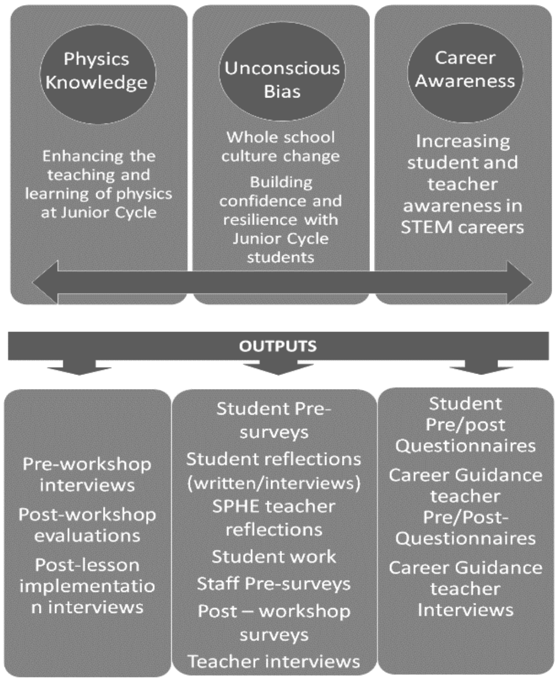

Figure 1: Three strand approach with data collection points

Recommendations from the Improving Gender Balance project in England (Institute of Physics, 2017) highlighted the importance of adopting a holistic approach in addressing gender stereotyping across the whole school environment. These key stakeholders in STEM education (school management, teachers and students) are identified in Figure 2. In addressing strand two (Unconscious Bias), all staff (principals, teachers and support staff) participated in whole school unconscious bias and resilience building workshops to inform a more diverse and inclusive approach to teaching and learning practices. Data for participating teachers was collected using pre and post-workshop surveys. In the coming months, small groups of students (typically 8-10 students) will be selected by teachers to represent the first year student cohort, and these students will participate in resilience building workshops focused on creating an awareness of the barriers that may be encountered in choosing STEM subjects/careers.

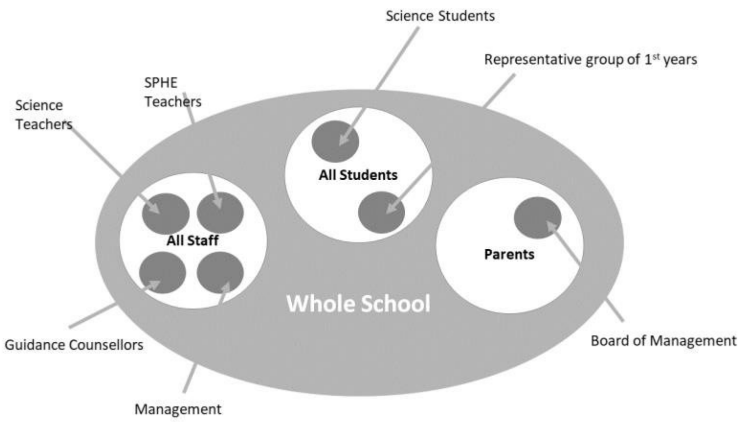

Figure 2: Key stakeholders in a whole-school approach to addressing gender imbalance

A whole-school approach has also been adopted to address awareness of the gender stereotypes that exist in subject selection and STEM career choices (Strand Three). Resources have been developed for this strand in collaboration with career guidance teachers to focus on increasing the awareness of students and their parents participating in subject choice meetings, career information sessions and welcome evenings for new students/parents.

FINDINGS

As part of this study, an open response survey was presented to over 250 second level teachers from across Ireland, asking them to identify the key challenges to participation of students, particularly girls, in STEM. The key challenges reported were: student's self-efficacy in STEM; students, parents and teachers lack awareness of STEM careers; impact of negative stereotypes and preconceptions; lack of resources for STEM subjects in school; and lack of awareness of STEM in society.

In the case of each of the seven pilot schools participating in this study, a baseline analysis of the profile of science teachers and the student participation in all STEM subjects in each school has been carried out. An initial audit of the school's website and policies was carried out using the following criteria to assess the schools' Science culture prior to participation in this study; Imagery, Placement of Physics in Subject List, Science Related Extracurricular Activities, Involvement in Science Events/Competitions, Gender Balance/Equality Policy and information on physics career options. The audits of the school website highlight the lack of awareness around unconscious bias and gender/subject stereotyping. None of the participating schools exhibited a policy for gender equality on their website. The imagery for physical sciences; Physics, Technology Engineering (where present) represented males only in the promotion of these subjects. Physics was listed in the last quartile or not listed at all for the Leaving Certificate subjects in four out of seven of the schools.

The central focus of the science teacher workshops was to enhance their physics pedagogical content knowledge as well as their awareness of careers in Physics/STEM. Science teachers were surveyed to identify key areas in which they required support to improve the teaching of physics at junior cycle. The topics identified included; light, speed, energy and electricity as concepts that teachers would like addressed in workshops. A series of teacher workshops were co-designed by the researcher in collaboration with a practising physics teacher to incorporate physics content knowledge, physics careers and strategies aligned with the junior cycle science specification (NCCA, 2013). The participation of teachers in in-school workshops varied; two schools accommodated workshops by providing teachers with substitution cover, one school accommodated workshops on their school half-day and the remaining science teachers participated in workshops after regular school hours. Individual science teacher engagement was recorded through workshop attendance and email interactions. Two University-based workshops were also facilitated by the researchers and 35% (18) of the science teachers participated in these one-day sessions. The evaluation of the impact of the participation in these teacher workshops on the teaching and learning of physics is ongoing.

The findings, from the Closing Doors report (Institute of Physics, 2013) in England, highlighted that that the best way to rectify gender imbalance in physics (and other subjects) is to address the problem through a combined approach of working across the school as well as in the subject areas, as schools showed that an imbalance in one subject tended to have imbalances across all subjects (Institute of Physics 2013). As part of the whole-school approach, the teachers from three schools participated in a whole school unconscious bias workshop. The aim of this workshop was to identify teacher biases, student biases and formulate strategies to address unconscious biases and gender stereotyping in the school and classroom environment. The participating teachers completed a pre-workshop survey and responses were collated from the 113 second level teachers, which included 33 science teachers, in this study. The majority of this sample of teachers 80% (90) disagree/strongly disagree that gender is already too imbedded in society for schools to do anything about it. Over half of the teachers 57% (54) agreed/strongly agreed that unconscious bias is considered in lesson implementation while only 43% (49) of the teachers agreed/strongly agreed that unconscious bias is considered in lesson planning- shown in Figure 3.

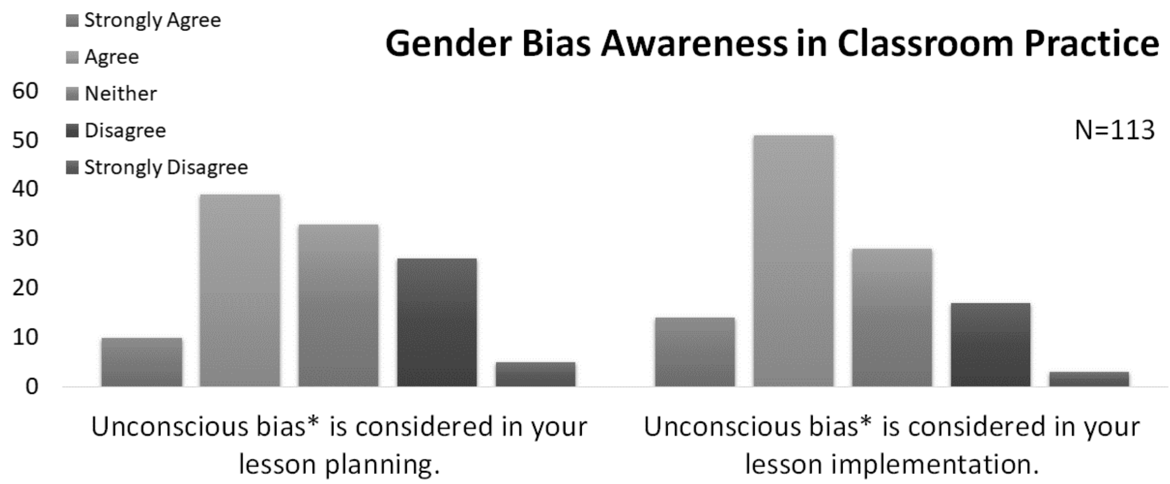

Figure 3: Teacher responses to the consideration of unconscious in lesson planning and implementation.

DISCUSSION

Initial evaluation in this study has identified the key challenges for STEM education in Ireland as student's self-efficacy in STEM; students, parents and teachers lack awareness of STEM careers; impact of negative stereotypes and preconceptions; lack of resources for STEM subjects in school; and lack of awareness of STEM in society.

Science teachers have identified their key challenges in teaching physics and these are being addressed through the design and implementation of science teacher workshops. The feedback from science teachers indicates that increasing their understanding of basic physics concepts is as beneficial to them as focusing on pedagogical approaches. This observation is supported by Laius' (2009) study of the lack of interdisciplinary knowledge among chemistry teachers.

The audits of the school website highlighted the lack of awareness around unconscious bias and gender/subject stereotyping. The imagery associated with physical science subjects was male dominated and Physics was generally listed at the bottom of the subject choices on offer at Senior Cycle. Teacher responses from surveys completed before participating in unconscious bias workshops indicated that staff knowledge of school policy, imagery and practices in relation to gender stereotyping was limited. As shown in Figure 3 above, 57% of teachers agreed/strongly agreed that unconscious bias is considered in their lesson implementation, although more than 75% of teachers indicated they had not completed any training.

The study described in this paper is ongoing, but these initial findings have highlighted the importance of research-practice collaborations to address the three-strands focused on in this study. The inconsistencies exhibited in the survey responses from all teachers further corroborate the need for a whole school approach to raising awareness of unconscious bias and gender stereotyping in school policies and practices that have a dramatic effect on participation and engagement on physics.

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The RDS STEM learning programme: Challenging science facilitation

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The RDS STEM Learning Programme is an initiative of the Royal Dublin Society (RDS) which was developed in partnership with the former St Patrick's College and Centre for the Advancement of STEM Teaching and Learning (CASTeL) - a multidisciplinary research team from Dublin City University (DCU). The pilot programme proposed a model of professional development for in-service primary school teachers which has had positive impacts in the teaching and learning of Science in Irish primary classrooms. The model provided participants with opportunities to explore, engage with and reflect on, a range of pedagogies and methodologies for teaching science though inquiry. The specific goals of the programme were to: i) to support and challenge primary school (principals, teachers and students) to engage with and understand science, technology, engineering and mathematics, and to demonstrate the relevance of STEM (science, technology, engineering, mathematics) subjects in the primary curriculum; ii) to support teachers in developing their Pedagogical Content Knowledge (PCK) in teaching STEM through inquiry iii) to develop a community of practice by providing participants with a forum to reflect on and share their experiences of teaching science. In the first pilot phase (2012 – 2015) there were two sub-programmes to the overall programme - a) the RDS STEM Learning Facilitator Programme – aimed at teachers with good competence and confidence in teaching science and mathematics who want to take their learning further, becoming peer leaders in STEM education and b) RDS STEM Learning Teacher Education Programme – aimed at teachers keen to increase their confidence and competence in STEM education. In the case of the individual teacher, the teacher became the facilitator in implementation of the Teacher Education Programme. This paper presents an overview of some of the findings from the evaluation of the pilot programme of the RDS STEM Learning Facilitator Programme, highlighting the complexity of the development of practice, and how impacts are subtly couched within everyday teaching and difficult to isolate. We will nonetheless note the positive impact that the Programme has had on participants' confidence and pedagogical knowledge of teaching through inquiry, particularly with regard to their confidence in teaching science and technology and establishing a reflective community of practitioners among the participants.

Keywords: primary science teacher, professional development

INTRODUCTION

It is well-documented that there is a need to systematically support teachers (Barak, 2008; Collins, 2014; Lawrenz, 1990) and children in developing higher-order thinking skills in Science across primary, secondary and tertiary education in Ireland. In particular, within primary school science and mathematics education in Ireland 'the teaching approaches used in many classrooms are not conducive to skills development; levels of child-led investigation and 'design & make' undertaken by students are relatively low and primary school children are not relating their school science experiences to the wider world or to future aspirations' (Varley et al. , 2008). It is further highlighted in the research literature that in comparison to their peers in other countries primary teachers in Ireland demonstrate 'below average levels of participation in continuous professional development, particularly where related to maths or science' and report 'average confidence levels for maths and below average confidence for science' (Eivers & Clerkin, 2013). It would also appear from data gathered from PIRLS and TIMSS (2011) that primary teachers in Ireland display a low level of professional collaboration for example, '27% of Irish fourth class pupils were taught by teachers who never or almost never collaborated in planning and preparing instructional materials with other teachers (ibid.)

To address the above challenges in primary education and to support existing initiatives in Ireland such as the National Literacy and Numeracy Strategy (DES, 2011) the RDS brought together strategic partners in education to develop an innovative and collaborative professional development programme. With a core focus on pupils' skills development, the *RDS STEM Learning Programme* aims to develop primary school teachers' pedagogical knowledge of, and confidence in, teaching science through inquiry while also developing a reflective professional learning community among primary school teachers. At the time that this Programme was initiated the existing models of science provision in Ireland emphasized the implementation of science as a prescribed activity and focused on providing teachers with an introduction to teaching the curriculum using a thematic approach. The *RDS STEM Learning Programme* therefore aimed to move beyond implementation and look deeper into the skills aspect and the process of teaching and learning science in conjunction with mathematics, technology, design and engineering.

The *RDS STEM Learning Programme* is informed by national and international research, by those with research expertise in science, education and pedagogy[*] [1]and importantly by the needs of primary school teachers. The development and delivery of the Programme was based on the learning outcomes of successful CPD programmes for teachers which identified several factors that could impact on the success of such programmes – such as length and duration[2](Timperley et al., 2007), focus on pedagogical improvement versus content knowledge (Coe et al., 2014), opportunities for trialing, implementation and reflection and ongoing support following such programmes (Joyce & Showers, 2002). Of emphasis within the literature is the importance of providing opportunities for teachers to trial approaches and pedagogies directly, to allow them to see that changes in their classroom practices can benefit student learning, as this will change their attitudes and beliefs towards particular pedagogy (Guskey, 2000)

RDS STEM Learning recognises that children's natural curiosity, creativity and critical questioning can be nurtured though inquiry-based science education (IBSE). Therefore participants engaged in scientific inquiry using pedagogies from the perspectives of Nature of Science (NoS) (McComas, 2012) and CASE (Cognitive Acceleration through Science Education) (Shaver, 1999). The Programme supported teachers to help children develop 'working scientifically', and 'design & make' skills as outlined in the curriculum (DES, 1999) and to integrate numeracy and literacy as integral components of a scientific investigation in the classroom.

Many teachers who are fearful of science or who have had limited education themselves in science may experience science as a set of activities to be completed in a prescribed manner with pre-determined results. Many feel that this is an active, hands-on approach to science teaching (Murphy et al., 2013; Smith, 2015) however, in the RDS STEM Learning Programme, the focus was on developing a competence in the teaching and learning of science. That is, where both teacher and student are active in the process of thinking about the science. This

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became the focus of the Programme - how to move teachers, and their students, from the practices of ‘doing science activities’ to becoming competent teachers of science where thinking was an integral part of the process.

Development and Rollout of the RDS STEM Learning Programme

In setting up the RDS STEM Learning Programme, focus group discussions with over 60 teachers identified their vision for science in primary school classrooms. Teachers summarised why they wanted to improve science education in the primary classroom: ‘To take Science beyond the 'wham, bang, whoosh' of activities, so that science will be alive in the classroom and will become an integral part of student's lives, and so that student-led problem solving, lateral thinking and confidence will be given importance’. Additionally, the teachers themselves wished to be part of a group of teachers to exchange ideas and experience. The two core strands to the initial pilot phase of the RDS STEM Learning Programme were a) the STEM Facilitator Programme and b) the STEM Teacher Education Programme.

The *STEM Facilitator Programme* involved 30 contact hours of workshops where participants worked collaboratively to explore ways of:

- Encouraging Creativity in Science;
- Developing students’ dialogical and thinking skills through Science;
- Integrating Science and Mathematics in the Classroom;
- Using Design and Technology in the Classroom;
- Guiding Child-led Investigation;
- Exploring Children’s Ideas of Science;
- Investigating Everyday Issues in Science.

Participants in the Facilitator Programme were primary school teachers who had a strong interest in science education and a proven commitment to develop and implement their own knowledge of teaching and learning. On completion of the first programme phase, the participants were instrumental in developing the goals, objectives, framework and content for the *STEM Teacher Education Programme* which they delivered to their peers. Delivery used a form of co-teaching for eight workshops across 20 hours to ensure that the Facilitators continued their own professional development and reflective practice.

The *STEM Teacher Education Programme* aimed to introduce new and innovative techniques to support primary school teachers to integrate open ended, problem solving activity within the classroom, allowing students to explore the primary science curriculum through child-led inquiry. This was a shorter course than the *STEM Facilitator Programme* delivered over 20 contact hours but was based on many of the same overarching principles.

The *STEM Teacher Education Programme* focused on how innovative approaches to teaching could be applied to the wide range of primary science initiatives and resource material already available. Using the question ‘What will a teacher learn/experience from this workshop?’ as a framework, the workshops within the *STEM Teacher Education Programme* also allowed time for reflection, discussion and sharing of experience from previous weeks’ sessions.

STEM Teacher Education Participants were primary school teachers who had some previous experience of participating in science activity but who wanted to further develop their teaching skills and knowledge in this area. Where possible, two teachers from a school participated in the Programme to allow sharing of experience as this provided a good foundation for the school community to build upon - especially as the planned future progression of *RDS STEM Learning* included the development of a whole school programme.

Participants of both Programmes were required to have the support of their Principal to participate in the course as they would put their learning into action in class and reflect on their classwork as part of the evaluation of the pilot Programme. Participation in the Programme was fully funded by the RDS and was delivered outside of school hours, every 2-3 weeks, allowing time for classroom practice and reflection between sessions. During this first phase 12 Facilitators and 38 teachers engaged with the pilot Programme.

METHODOLOGY

A two-phase approach was taken to measure the impact and effectiveness of the Programme through a structure of continuous feedback and reflection. The data which were collected throughout the pilot was subject to review by the authors of this paper, in addition to being used within the independent external evaluation (RDS STEM Learning, 2015) - the key outcomes will be included in this paper.

Data Collection and Review

1. Surveys - Baseline surveys of teachers' attitudes, perceptions and experiences were captured at the beginning, middle and end of the Programme participation.
2. Reflection Sheets - Teachers completed Reflection Sheets after implementing workshop ideas and approaches in the classroom. This captured their change in emphasis from activity focus to looking in greater depth at the children's engagement and thinking process.
3. Reaction Sheets - Teachers' engagement with and reflection on the content and implementation of each workshop of the Facilitator Programme was captured through written feedback on Reaction Sheets - this contributed to the refinement and development of the pilot Programme week to week.
4. Discussion and Focus Groups - Group discussion sessions focused on development of the RDS STEM Learning Teacher Education Programme workshops were recorded to determine the key aspects that the teachers felt were important to bring into the second phase of the Programme.
5. Qualitative interviews - These were undertaken as part of the external evaluation
6. International literature review - In addition to the data collection across Programme delivery the independent evaluation set out to benchmark RDS STEM Learning against national and international primary teacher CPD programmes.
7. The external evaluation also reviewed the Programme objectives in accordance with the five OECD evaluation dimensions of relevance, effectiveness, efficiency, impact and sustainability to draw evidence-based conclusions as to the achievements and impact of the pilot, and recommendations about its continuation and future development (RDS STEM Learning, 2015).

RESULTS

It is apparent from the data that participation in the RDS STEM Learning Facilitator Programme greatly increased participants' confidence and competence in teaching science through inquiry. It was also apparent that participation in the programme was particularly effective in establishing a community of reflective practitioners - participants reported that the Programme involved and encouraged peer learning and collaboration, one participant reporting that '*I cannot overemphasise the importance of the collaborative nature of the Programme. I really found this most beneficial'*. The data also indicated that the generation of an atmosphere where teachers felt comfortable to openly share their experiences and vulnerabilities was instrumental to this outcome; '*The culture and tone of the Programme very much supported engagement in reflective practice. The discussions every week with teachers and the open and friendly atmosphere in the face to face sessions and on the online forum helped make it a place where I felt comfortable in saying when things I tried went well and when they were disasters'* (Final Participant Survey).

It is interesting to note that participants' experience of RDS STEM Learning was different, and more positive, than their experiences of other CPD initiatives. On reflection within a focus group discussion participants agreed the following elements as the key differentiators between RDS STEM Learning and other CPD initiatives, reflecting that RDS STEM Learning has (RDS STEM Learning Interim Report, RDS, 2014):

1. Encouraged a different approach to teaching, (*participants are*) now teaching in a different way, asking different questions. Children are going home and talking about science;
2. Focused on the process and skills, not just recipe-style activity;
3. Been a kinaesthetic experience, learning by doing and not hand-out based;
4. Been sustained - course taking place over long period was more beneficial than short course;
5. Homework (*for participants*) and opportunity for trialling activities during STEM workshops was of benefit – feedback was shared in the group, from colleagues and children;
6. Been interactive - Reflections at the start of each session, good for sharing ideas and experience, feeling of being in a club;
7. Provided (*participants*) an opportunity to input into the development and direction of CPD programme.

What was notable at this juncture was that, despite highlighting these as key elements which they themselves had found most beneficial, in the process of preparation for Teacher Education Programme these same teachers first thought of the 'what' - suitable activities, before setting out the 'why' – ie what was to be achieved within the Teacher Education Programme and why it was important. This emphasises the importance of a sustained intervention to support teachers to deepen their understanding and to reflect on their practice over time on their journey to becoming peer leaders in education.

Analysis of teachers' reflections captured within the Reflection and Reaction Sheets across the duration of the Programme shows the development in process from simply 'doing science activities' to thinking through science for example, *'The past fortnight has shown me that science has many different facades and sometimes it may be good to lead the children in scientific discussion...its ok for them not to be doing hands on activities all of the time.'* (Participant response to workshop captured within Reaction Sheet)

There was an emerging change in teachers' thinking, with the majority reporting an increase in their awareness of the importance of thinking about science as well as about their students' experience of science (RDS STEM Learning, 2015) '*It showed me that I find some of the reasoning and thinking skills necessary for the activities quite challenging. It was good to feel a bit of what the children might feel in my classes when trying to come up with a solution to a problem'* (Participant response to workshop captured within Reaction Sheet). In addition the notion of achieving the 'right answer' dissipated over the course of the Programme from an *'initial wariness'* to a confidence that *'There was a definite positive impact on the children's* *learning due to the classroom practice as a result of the STEM workshops. The children became more confident that they did not have to know the right answer when setting out on an investigation'* (Participant reflection captured within Reflection Sheet).

What has come through overall is that Facilitator participants have begun to use scientific investigations as a vehicle to develop literacy and oral language skills in their students, while an increase in child-led classwork is encouraging children to collaborate and solve problems together. There is some evidence - stronger in some areas than others - of a greater use of inquiry skills, open-ended questions and Design and Make techniques; and a deeper emphasis on skills development among teachers. In addition, the nature of the feedback from teachers changed from a focus on an activity where *'children stayed on task'* to observing their students' learning *'I would now put more emphasis on encouraging children to think more about why they are doing what they do in science investigations - to communicate their thoughts aloud, as well as devising tasks that would challenge their thinking'* (Participant reflection on their classroom practice captured within Reflection Sheet).

Overall it can be observed that participation in RDS STEM Learning has supported teachers to create a classroom environment where students are encouraged to question, reason and explain their thinking process, and that teachers have a greater awareness of the importance of focusing on skills development in the children. However, the Programme also highlights the complexity of the development of practice, and how impacts are subtly couched within everyday teaching and difficult to isolate, for example in one reflection *'Sometimes I don't spend enough time actually teaching skills, showing children the difference between observations and inferences. I get frustrated when trying to get children to talk about what's going on in an investigation and they are mixing up what they saw and what they think is happening or why – but of course I have never taken the time, or knew how to help them develop those key skills'* (Participant reflection on their classroom practice captured within Reflection Sheet). This reflection is a first step to moving from a change in thinking about their science teaching leading to a longer-term change in their teaching practice.

KEY LEARNINGS AND NEXT STEPS

On review of the first phase of the pilot Programme it is clear that the Programme has impacted on an individual teacher level and that at a Programme level it has been a departure from existing models of CPD in Ireland.

On an individual teacher level:

- The pilot **Programme** has delivered significant measurable impact in the areas of teacher confidence and ability, and student engagement.
- Participants in the pilot **Programme** began to shift from measuring success in teaching in terms of '*what a child knows*' to the way in which a child can think.
- Teachers are now much more reflective of how lessons are going and how they can be improved.
- An additional impact for students was also noted; that they observed that '*their teachers' education was continuous and not static*'

(RDS STEM Learning, 2015).

At a Programme level:

- International benchmarking and literature review has shown that a balance between pedagogical improvement and the provision of subject specific knowledge is imperative in effective CPD programmes; the pilot **Programme** has demonstrated effective practice in these areas.

- STEM CPD programmes of longer duration tend to have better outcomes for students and teachers; while not reaching the internationally recommended length, the pilot **RDS STEM Learning Programme** has demonstrated a positive departure from existing CPD offerings in Ireland.
- The engagement of external academic experts in pedagogy and CPD, and the collaborative delivery model of the pilot **Programme** has yielded positive outcomes.
- There is no international consensus on benchmarking effective CPD; the pilot **RDS STEM Learning Programme** has the potential to demonstrate innovative practice in this area.

  (RDS STEM Learning, 2015)

The RDS STEM Learning Programme has clear strategic development goals and the capacity to develop over 5-year timeframe, with substantial increased impact and scale. The ambition achieve a change in thinking among participants, to then lead to a change in classroom practice requires a sustained and deep intervention over time. As a model of professional development RDS STEM Learning has been ambitious and highlights the importance of evidence based programme development, linking best practice in educational research with the reality of everyday classroom practice to support participants in a continuum of learning.

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Investigating students' learning of differential equations in physics

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There are numerous cases in physics where the value of a quantity and changes in that quantity are related. For example, the speed of an object depends on its acceleration; the radioactivity of a sample depends on the amount of the sample present. Except in highly idealized settings, the analysis of these cases requires students to recognize, set up, and solve an ordinary differential equation (ODE).

This project is a multi-stage investigation that began by identifying the issues experienced by physics students during their study of ODEs before addressing them through the design and implementation of a set of fifteen tutorials. Having surveyed a cohort of physics students who completed a typical service module on ODEs, we found that many of them possessed a fragmented concept image of ODEs and insufficient instrumental understanding.

The workshop will outline the primary features of the intervention, one of which is the inclusion of modelling with first order ODEs. The participants will then be guided through the worksheets on modelling to experience the intervention from the students' perspective. The closing portion of the workshop will be a facilitated discussion that will begin with participant feedback on the worksheets before moving to tertiary service mathematics in general.

Keywords: Physics Education, Mathematics Education, Service Teaching

Blurring the boundaries between informal and formal science in the classroom

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This workshop is for attendees who wish to i) develop informal science activities (also known as outreach) or, ii) incorporate aspects of informal science activities into the formal classroom. Outreach programs are designed to be engaging How can we design them and while also making them effective and appropriate for classroom settings. In the workshop, we will work with participants on:

- Designing activities aligned with their own interests, their communities' interests, and curriculum needs.

- Defining the activities' goals, program content, and methods of evaluation. Discuss guidelines with the purpose that attendees will work on their ideas and getting feedback from fellow attendees and organizers. A. The focus of the workshop will be on big picture planning to establish a broader plan of action for the design of the types of activities.

The workshop will include discussion of challenges to assess informal science-like activities, and research in these environments. Again, organizers will present some guidelines or resources, but a significant amount of time will be used for the attendees to consider what will be the best assessment tools/practices for the program they designed.

Finally, we aim to connect people interested in facilitating research-driven informal science activities to build community and collaboration between such individuals who are often marginalized in their departments or whose efforts in informal are considered tangential to "formal" science activities. Workshop attendees will take away ideas about how to leverage effective design and assessment of informal settings towards increased resources and support in their local contexts.

Keywords: Informal science, Design-based implementation research (DBIR), teacher's professional development.

SMEC 2018 Early Career Researchers' Event

As part of SMEC 2018, the Centre for the Advancement of STEM Teaching and Learning hosted the SMEC Early Career Researchers' Event. This is the first time that the SMEC conference had a strand dedicated to early career researchers. Researchers (ranging from PME to PhD) presented posters on their research, and took part in small group discussion. There were 18 posters presented on the day, with the research spanning all STEM disciplines. 22 researchers took part in the small group discussions, where they shared more insights into their research and got the opportunity to make valuable connections. Dr Aisling Leavy, Mary Immaculate College and general editor of Irish Educational Studies provided a wonderful close to the day with a talk entitled 'Getting published: Insights from a journal editor'.

SMEC 2018 Early Career Researchers' Event
Monday 25th June 2018
Dublin City University, St Patrick's Campus

Hosted by the Centre for the Advancement of STEM Teaching & Learning, Dublin City University

12.30-1.45 Registration and poster hanging *Library reception space*
1.45 – 2.00 Welcoming Address
2.00 - 3.30 Poster session *Library reception space*
Tea/Coffee
3.45 - 4.30 Small group discussion session *Lego Innovation Studio* Focussed discussion groups where attendees can share ideas, solutions and their experiences of their research journey to date.
4.30 - 5.15 Q&A and Presentation by Dr. Aisling Leavy *Lego Innovation Studio* Dr. Aisling Leavy, Mary Immaculate College and editor of Irish Educational Studies will give a presentation on transforming graduate research into publications.

IOP | Institute of Physics In Ireland

SMEC Early Career Researchers' Event is kindly supported by the Institute of Physics in Ireland

Early Career Researchers’ Event Poster Winners

The Institute of Physics in Ireland kindly sponsored prizes for best poster. The panel of judges were Professor Anna Steinweg, Universty of Bamberg, Germany; Dr. Aisling Leavy, Mary Immaculate College, Limerick; and Dr. Cliona Murphy, Associate Director CASTeL, Dublin City University Institute of Education.

The high quality of all posters was praised but the following posters were recognized as of outstanding quality. Congratulations to all!

First prize

> **Teacher and student experience in the context of SSI: A comparison of two approaches**
>
> Ruth Chadwick

Runners Up

> **Development of a science board game for the teaching and learning of astronomy topics**
>
> Adriana Cardinot and Jessamyn Fairfield

> **Scratch and Computational Thinking: A Computer Programming Initiative in a Girls Primary School**
>
> Claire Carroll

SMEC Early Career Researchers’ Event is kindly supported by the Institute of Physics in Ireland

Teacher and student experience of inquiry in the context of SSI: A comparison of two approaches

R. Chadwick, Dr. E. McLoughlin, Dr. O. E. Finlayson, CASTeL, DCU

Introduction

Inquiry in the context of SSI is increasingly being embedded into the school science curricula of countries around the globe, with the aim of developing the skills and knowledge of scientific inquiry in students (NCCA 2015).

Inquiry can be described in two ways. Firstly, as the skills and knowledge that students learn. Secondly, as a pedagogical approach that is student centred and collaborative, uses investigative approaches, is described according to the level of student or teacher control and is assessed formatively and summatively (Colburn 2000).

Socioscientific Issues (SSI) can be used as the context for inquiry. SSI are scientific topics with societal implications, which are controversial and contemporary (Sadler 2009). SSI can be used to encourage students to take action on an issue of local or global importance (Bencze 2017).

Methodology

Two qualitative case studies were carried out that aimed to exploring the skills and knowledge of inquiry that were developed and assessed when teachers used inquiry approaches and SSI contexts. The case studies used thematic analysis of field notes from lesson observations, teacher interviews & secondary documentation (student work/questionnaire, teacher lesson plans).

Case study A

One teacher & class of 19 second year (aged 13-15) students.

Experimental inquiry (SSI context not emphasised)

SSI context: Animal rights and the use of animals in science

Woodlice Investigation

Teacher experience: pedagogical approach

Open experimental inquiry: Teacher facilitates students to carry out an experiment and devise their with own question and method for investigation

Student experience: Skills and knowledge

- Students *propose investigatable questions.*
- Students *state justified hypotheses,* using *scientific knowledge,* and *plan and carry out experiments.*
- Students *evaluate and make changes to experiments.*
- Students *present and analyse data* and *explain scientifically* using *scientific knowledge* when drawing conclusions

Animal rights and use of animals in science

Guided discussion inquiry: The teacher sets the question for discussion and facilitates discussion

Students discuss and *explain scientifically* their views, drawing on *scientific knowledge* of the implications for society

Students show *self-management* throughout

Case study B

One teacher & class of 21 first year (aged 12-14) students.

SSI context: Traffic congestion in the local area

SSI context: Climate change denial

"The concept of global warming was created by and for the Chinese in order to make US manufacturing non-competitive"
@realDonaldTrump Nov 2012

The Transport Problem

Teacher experience: Pedagogical approach

Guided discussion inquiry: Teacher provides the problem and facilitates student discussion and asks probing questions.

Student experience: Skills and knowledge

- Students *work together* to come up with solutions to a problem
- Students *present evidence* (solutions) to classmates and *explain* solutions using *scientific knowledge*
- Students *evaluate* solutions

Letters to Trump

Secondary research and guided discussion inquiry: Teacher provides the problem and facilitates research.

- Students *work together* to *research* an issue (climate change)
- Students *distinguish arguments based on science* using *scientific knowledge*
- Students *present evidence* in a letter and *explain scientifically* using *scientific knowledge*

Conclusions and implications

The teacher experience centered around the pedagogical approach to inquiry and the student experience focused on the skills and knowledge developed and assessed. The different pedagogical approaches used, influenced the skills and knowledge developed and assessed. In case study A, the pedagogical approach was mainly an experimental inquiry with some guided discussion and the skills developed were related to experimental investigations. In case study B, the pedagogical approach was guided discussion and secondary research, and the skills developed and assessed related to critical evaluation of evidence. The knowledge developed and assessed was dependent on the SSI context. In case study A, the SSI context was not emphasised and the students did not relate their knowledge to the impact on society. In case study B where the SSI context was central to the inquiry, the knowledge developed related to the implications for society.

This means that teachers should choose the pedagogical approach to inquiry based on the skills and knowledge they aim to develop and assess.

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DEVELOPMENT OF A SCIENCE BOARD GAME
for the teaching and tearning of astronomy topics

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INTRODUCTION

A number of studies have highlighted the use of Game-Based Learning (GBL) as a student-centred approach in which incorporates learning content into games, allowing students to develop and to exercise a wide range of skills [1].

This research study aims to investigate the use of a novel board game for the teaching and learning of astronomy among post-primary students.

METHODOLOGY

The study was organised following the Design-Based Research (DBR) methodology principles in order to construct a collaborative, flexible, iterative and interactive project [2].

It allowed us to identify which different variables of the Game-Based Learning approach that play a role in the failure/success of our game besides guiding the learning of astronomy topics from the new JC Science Syllabus.

A total of 119 secondary students based in different counties across Ireland and the UK took part in the pilot trial (M=14.84 years, SD=1.06, 32.8% male, 66.4% female and 0.8% blank).

EVALUATION

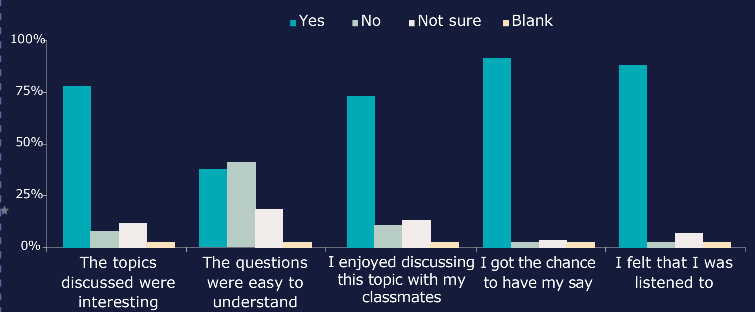
Mixed method (quantitative and qualitative research elements) to collect data, analyse, interpret and contextualise our findings. Data was collected via:
- pre and post-test;
- feedback survey;
- focus group.

THE GAME

The game consists of a board, three types of cards with different levels of questions about the Solar System and scientists, six-sided die and instructions for playing the game.

RESULTS

Preliminary results indicated that our game:
- foster communication skills;
- helps students to internalise astronomy concepts;
- promote positive views of physicists and their work.



FUTURE WORK

We plan to investigate further how teachers can integrated board games and the science curriculum as a continuous practice for the teaching of astronomy topics. We also plan to examine how collaborative interaction among players could affect learning gains.

ACKNOWLEDGMENTS

This work was funded by:
- CAPES-Brazil;
- Institute of Physics in Ireland (IOP).

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CAPES NUI Galway OÉ Gaillimh IOP Institute of Physics in Ireland FAIRFIELD LAB

Scratch and Computational Thinking: A Computer Programming Initiative in a Girls Primary School

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Abstract

In recent years there has been an unprecedented push, by governments of advanced nations, including Ireland, to improve the quality of education, and revitalise interest, in STEM (Stem Education Review Group, 2011). Consequently, the introduction of Computer Science subjects to the school curriculum at primary and post-primary level has gained momentum. The aim of this research is to assess what benefits, particularly in relation to computational thinking, can be gained from the use of a visual programming language, Scratch, in a girls primary school. Brennan and Resnick (2012) developed a computational thinking framework that examines three key dimensions of computational thinking: *computational concepts* (the concepts programmers engage with as they program, such as iteration and synchronisation), *computational practices* (the practices programmers develop as they engage with these concepts, such as remixing and debugging), and *computational perspectives* (the perspectives programmers develop about the world and about themselves). Using this framework, this study examined the development of students' computational thinking skills during a ten week programming initiative. Data were collected from Project Portfolios Analysis, Design Scenarios (Brennan and Resnick, 2012) and Participant Observation. This poster describes the findings, and outlines the computational thinking concepts developed, the practices employed and participant perspectives as a result of engaging in the programming initiative.

Introduction

In the face of unpredictable and unprecedented change, European and International policies have acknowledged the importance of developing education systems responsive to the demands of a knowledge-based society. For example, the eEurope 2002 Action Plan observed that 21st century schools require curricula to develop different knowledge, skills and dispositions than those required in the 20th century. In 2006, Jeannette Wing wrote an influential article on computational thinking. She advocated for adding this new competency to every child's analytical ability. Since then, the introduction of computational thinking skills to school curricula at primary and post-primary level have become widespread. In the Action Plan for Education 2017, the Irish government announced their intention to reform the primary mathematics curriculum, to include programming. Computational thinking has become a catchphrase, as government education advisors and curriculum developers explore possible directions for the new curricula.
Computational thinking is a problem-solving process which originated in the field of computer science but is increasingly being recognised as an essential competency for all fields. The idea that programming is a key vehicle in the development of computational thinking has gained traction in educational institutions across the globe. However, despite considerable international interest in integrating computational thinking to school curricula, its successful integration still faces several challenges (Figure 1).

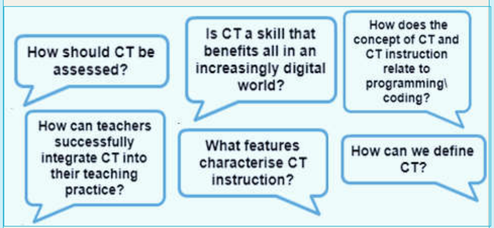

Figure 1: Challenges facing the integration of CT to school curricula (ET 2020 Working Group on Digital Skills and Competences, 2016)

Method

The 90 participants were from an urban, girl's primary school. It was a convenience sample chosen due to accessibility.

Class	Third	Fifth	Sixth
Number of Pupils	32	28	30

Table 1: Participants by Class

Students worked in pairs with a partner assigned by their teachers with input from the students themselves. The initiative took place over a ten week period, with one hour sessions each week (Table 3). 'Scratch', a visual programming language was chosen as the programming tool for the initiative. The first five sessions focussed on learning the basic functions through a series of self-paced exercises with step-by-step instructions to create their first animations. In the following weeks there was no explicit programming instruction. Instead, the sessions were run based on a 'learning on demand' model (Kafai and Ching, 2001). In this model the students develop ideas of what they want to program, and either asked their partner, another pair or the instructor for assistance. Data collection methods were synchronised with the teaching phase (Table 2). Dr Scratch was used to analyse the scratch projects in terms of seven concepts: abstraction and decomposition, logic, data representation, parallelism, synchronisation, flow control and user interactivity (Moreno-León and Robles, 2015). Data collected from observations, the student logs and the post-programme questionnaires was used to examine the development of computational practices and computational perspectives.

Week	0	1-10	Post
Phase	Pre-Teaching Phase	Teaching Phase	Evaluation
Data Collection	Pre-Programme Questionnaire	Observation Design Scenarios Project Portfolio Student Logs	Post-Programme Questionnaires Focus Groups

Table 2: Synchronisation of the data collection methods with the Teaching Phase

Results

At this stage in the research the researcher is engaged in preliminary data analysis. The following section outlines initial findings using the three key dimensions of computational thinking: *concepts, practices and perspectives*.

Computational Concepts

Twenty five projects final projects were analysed. The projects ranged from fruit drop and hide and seek games to animated stories of classics such as Alice in Wonderland, and original animations. All of the projects analysed were evaluated as developing. The average computational thinking score was 10.2 and the median score was 10. There were three projects which the Dr Scratch application was not able to analyse.

Week	Learning Objective	Activity
1	Students will: - be introduced to the concept of **sequencing**. - experiment with a range of scratch blocks in the Control, Motion (coordinates), and Sound categories.	Create an animation incorporating movement and images.
2	Students will: - become more familiar with the concept of sequencing. - be introduced to the concepts of **events, synchronisation** and **data** (position, direction, size etc.). - practice **experimenting and iterating** while creating projects.	Create a knock knock animation using images, sound and movement.
3	Students will: - develop greater fluency with computational concepts (events, sequencing and data). - be introduced to the computational concepts of **conditionals** and **parallelism**. - gain familiarity in **reusing and remixing** while designing their game.	Create a race game which uses sensing to effect a change in the game.
4	Students will: - be introduced to the computational concepts of **looping** and **data** (variables). - practice **abstracting and modularizing** while designing a game for their classmates. - demonstrate greater persistence and creativity in finding solutions to problems.	Create a pong game with sounds, scoring and other effects.
5	Students will: - be introduced to the computational concept of **operators**. - develop greater fluency with the computational concepts of **parallelism, conditionals** and **data** (variables). - become more familiar with the computational practices of **experimenting and iterating**, **testing and debugging, reusing and remixing,** and **abstracting and modularizing.**	Build and extend a fruit drop game project using operators and sensors to track lives and keep the score.
6	Students will: - set out their own goals for a project. - build on all previously learned skills.	Plan, create and edit a Scratch project of their choosing.

Table 3: Outline of activities for each week

The highest scores were achieved in the **synchronisation** and **parallelism** concepts. 84% of the projects scored maximum points (3/3) in both these concepts. Lower scores were achieved in **flow control** in the pupils' projects. Although all projects scored at least one point (which required the creation of a sequence of blocks), only 40% of the projects analysed scored more than one out of three. Scoring more than one on the flow control concept required the use of iteration. There are two types of iteration: count-controlled and condition-controlled. Count-controlled loops repeat the same steps a specific number of times, regardless of the outcome. A condition-controlled loop will keep repeating the steps over and over until it gets a specific result. None of the projects contained condition-controlled loops, which is a more advanced programming construct. The projects that contained the count-controlled loops mostly used it for movement in games or stories.

Data Representation was underutilised in games and animations. Data representation is the set of information about the characters, for example the position of each character, the direction it is pointing, size, etc. In addition data such as the level, elapsed time, the rating, the lives, the rewards collected are all examples of more complex data representation. All of the final projects scored one for this concept. In most cases this meant that they tended to assign information about the sprite at the beginning of the game or animation but not make changes to it during the course of the project. **User interactivity** was low in all the projects, again no project scored more than one out of three. In most cases this was personal choice as students did not necessarily require user input to determine how the program ran. However, this was a concept which the students found difficult when covered in the early sessions. The lowest score was achieved in the **logic concept.** Only two of the projects achieved any points in the logic concept, and in both cases this was one out of three. This concept is assessed by checking for the presence of certain constructs which cause the program to behave differently depending on certain conditions. In stories these constructs are not important as stories usually have a linear structure. However, in games these are essential to perform different actions depending on the condition. For example, 'if the time equals 0, say game over' or 'if touching fruit change score by 1'. As most of the students were new to programming, they learned about several computational concepts during the ten week initiative.

Computational Practices

In order to employ these concepts the students had to engage in computational practices, such as experimenting and iterating, testing and debugging, reusing and remixing and abstracting and modularizing. The following are some examples of computational practices that were observed during the ten week programming initiative.

Experimenting and Iterating:

"I wanted it to look like it [the ball] was getting smaller as it got farther away but when I played it, the ball just disappeared and came back smaller, so then I used the change size one [block] over and over instead and it looked much better. It took lots of tries to get the timings right"

Testing and Debugging:

"I want it to say 'I won' when it reaches the finish line but nothing is happening when it touches the white line."

"The forever makes sure that if it ever touches it [the white line] it will work."

Reusing and Remixing:

"I used the hide and seek game but I added my own style to it. I changed the characters to be minions, cause I like them. Then I used the music from the minions movie. I added levels and at the end I had a 'Game Over' background that tells you how you scored. I also put in a 'cheat', don't tell Marianna. I press this button [presses K] and my characters score goes up by 5."

Abstracting and Modularizing:

"Well in my catch game I just had the cute dog falling from the sky but when Jenny played it she said it was too easy. She just kept pressing the buttons and going over and back and didn't even look and her score just kept going up. So I added in a cross dog and if you catch the cross dog you get minus points so then she had to look [at] what she was doing and avoid the bad ones."

These findings will have to be examined further to ascertain the types of experiences that afford students the opportunity to develop these practices.

Computational Perspectives

'Computational perspectives' refer to the worldviews that students develop as they engage with digital devices (Kafai et al, 2016). The questionnaires and the classroom observations provided valuable insights into the students' developing computational perspectives. In particular, the students recognised the value of programming in the development of 21st century skills such as perseverance, team work and creativity (Figure 2).

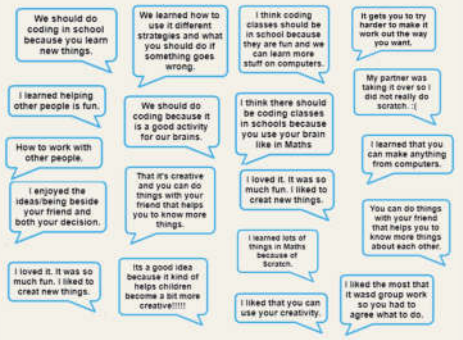

Figure 2: Computational Perspectives

This data from the teaching phase and the post-teaching phase will be compared with data from the pre-teaching phase to explore how students' computational perspectives developed during the initiative.

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