SMEC 2014

Thinking Assessment in Science and Mathematics

Hosted by:

CASTeL & SAILS

Strategies for Assessment of Inquiry Learning in Science

Science and Mathematics Education Conference

Dublin City University

24th & 25th June 2014

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WELCOME ADDRESS

The SMEC 2014|SAILS conference was organised by the Centre for the Advancement of STEM Teaching and Learning (CASTeL) in partnership with the Strategies for Assessment of Inquiry Learning in Science (SAILS) project. This conference was hosted at Dublin City University, Ireland on 24th and 25th June 2014 with the theme *Thinking Assessment in Science and Mathematics*. The plenary speakers at this conference were Wynne Harlen, University of Bristol, UK; Benő Csapó, University of Szeged, Szeged, Hungary; Malcolm Swan, University of Nottingham, UK; Cecília Galvão, Institute of Education, University of Lisbon, Portugal and Paul Black and Chris Harrison, King's College London, UK.

SMEC2014 is the sixth in the series of biennial international Science and Mathematics Education Conferences hosted by CASTeL at Dublin City University and St. Patrick's College Drumcondra The purpose of this conference series is to provide an international platform for teachers and educators to discuss practices and share their experiences in the teaching and learning of STEM at and across all educational levels. Url: www.castel.dcu.ie.

The SAILS project supports teachers in adopting inquiry based science education (IBSE) in second level classrooms across Europe. The SAILS project is focussed on developing appropriate strategies and frameworks for the assessment of inquiry skills and competences to prepare teachers not only to be able to teach through inquiry, but also to be confident and competent in the assessment of their students' learning. The SAILS consortium are providing teacher education programmes in inquiry and assessment across the twelve participating countries and encourage teachers to share their experiences and classroom practice of inquiry approaches to teaching, learning and assessment. Url:www.sails-project.eu

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Deirdre McCabe, *CASTeL, Dublin City University, Dublin 9, Ireland*
Paul van Kampen, *CASTeL, Dublin City University, Dublin 9, Ireland*

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ISSUES IN POLICY AND PRACTICE IN THE ASSESSMENT OF INQUIRY-BASED SCIENCE EDUCATION

Wynne Harlen

University of Bristol, UK

The increased attention to assessment of students' achievement in the past 30 or so years, although welcome in many respects, has thrown up very many questions, challenges and matters for research (the meaning of 'issues' in this context). In this paper I first briefly raise four dilemmas facing assessment in general, before turning to questions that rise in relation to assessment in inquiry-based science education (IBSE) in particular. The four issues arise from conflicts, or disconnects, between what we would like, or ought, to be able to accomplish through assessment and what happens in practice.

DESIGNING FORMATIVE ASSESSMENT LESSONS IN MATHEMATICS

Malcolm Swan

University of Nottingham

Formative assessment is the process by which students and teachers gather evidence of learning and then use it to adapt the way they learn and teach in the classroom. In this talk I describe a design research project in which we are attempting to develop and integrate "formative assessment lessons" into classrooms across the US and the UK. In this, we have found it necessary to distinguish lessons for concept development, where the focus is on interpretation, from lessons that are intended to foster problem solving processes, where the focus is on comparing strategies for inquiry in non-routine situations. Principles for the design of these lessons will be described and illustrated. The primary question throughout is: How can we design materials that allow teachers to promote inquiry and that are also adaptable to student learning needs?

ASSESSMENT IN THE PEDAGOGY OF INQUIRY

Paul Black and Chris Harrison

Department of Education, King's College London, UK

Reality beyond the classroom presents adults with complex and ill-structured tasks. Inquiry-based science learning can help prepare pupils to meet this challenge, because it can link the capacity to select, expand and apply knowledge in ways that respond to the demands of each task. This ambitious aim requires a parallel development of knowledge, understanding, strategies and skills. The talk will explore how inquirybased learning can help achieve this aim. It will stress that both the choice of classroom tasks, and the formative feedback that aims to guide learners as they tackle such tasks, are essential. Further aspects, notably the positive role that summative assessment can play, and the value of collaboration between teachers in refining their summative strategies, will also be emphasised.

DEFINING AND ASSESSMENT OF COGNITIVE OUTCOMES OF INQUIRY-BASED SCIENCE EDUCATION

Benő Csapó MTA-SZTE

Research Group on the Development of Competencies Institute of Education, University of Szeged, Szeged, Hungary

A large number of aims are associated with science education, among these the most frequently expressed ones are (1) the establishment of a solid scientific literacy for all young people, (2) the improvement of the thinking skills and (3) the preparation of a growing proportion of a given generation for science related professions. Although in a number of countries the education system cannot meet these goals and the interest in science is declining, new expectations have emerged, e.g. the improvement of the '21st century skills', such as creativity, critical thinking and problem solving. To make science education more effective and more motivating and to meet these new expectations new teaching and learning methods are needed. Among the emerging new approaches, Inquiry-Based Science Education (IBSE) is the most prominent one. The FP7 initiative of the European Union has also supported a number of IBSE projects. However, the need for assessing the outcomes of IBSE emerged only in recent times, as assessment – especially formative assessment taking place during the teaching-learning process acknowledging the importance of feedback in student's learning – has come to the forefront of research and development. A variety of IBSE implementations exists today; their differences can be characterized in terms of interpretation of inquiry, depth of changes compared to traditional teaching, areas of application, complexity of inquiries, and length or frequency of the application of the relevant activities. To make the outcomes of IBSE assessable, they should be operationalized and described in a measurable format. This presentation shows how theoretical and empirical sources can be identified for developing scientifically established assessment frameworks. It elaborates how the gap between general goals of teaching and the classroom processes can be bridged by the application of theories and results of cognitive psychology. Three main groups of theoretical sources will be discussed: (1) research on social expectations and needs related to science education and contexts of application of scientific knowledge mastered inside and outside of school, (2) theories and empirical results on the structure and development of students' cognitive abilities, and (3) theories on the organization of professional/disciplinary knowledge (expertise). The last part of the presentation will focus on classroom work and other practical aspects of assessment. It outlines the general approach to framework development and shows several examples both for the skills identified in this process and for the science units which may be used to practice and assess students' inquiry and reasoning skills.

WHY TEACHERS SHOULD WANT TO FOLLOW OUR CURRICULUM DESIGN?

Cecília Galvão

Institute of Education, University of Lisbon, Portugal

The change of a curriculum it is not that difficult if we can add the political will and some imagination to the research and knowledge about the subject. What is difficult is to implement it if it includes the change of teachers' practices. How can it be done? How can we convince teachers to follow the new ideas? How can the structural, organizational and personal resistance be overcome? Taking as a starting point the competence-based science curriculum in Portugal, for lower secondary education (from its conception and implementation in 2002 until its evaluation ten years later), I'll discuss teachers' professional development in close relation with their problems with the proposed changes and I will try to understand teachers' reasons and difficulties. Taking these findings as learning, I'll introduce, as an organizational example, a training programme on experimental science for teachers in primary school, which was a very successful experience. A third example comes from SAILS and the Portuguese Community of Practice. We expect it to work as a virtual place where change is possible. The concept of shared reflection underlines all the situations presented. I'll try to defend the idea of teachers and researchers working in close collaboration as a way to smooth the path to personal changes. It is important to support teachers with the definition of their strategies to explicitly address important questions regarding the structure, design, assessment and development of inquiry activities, but the main issue that emerges is the need to reflect on how to promote an effective self-appropriation by teachers in a process of curriculum change.

INTRODUCING THE ASSESSMENT FOR LEARNING AUDIT INSTRUMENT: A TOOL DEVELOPED TO GUIDE SCHOOL BASED PROFESSIONAL DEVELOPMENT

Michael O'Leary and Zita Lysaght

St. Patrick's College, Drumcondra, Dublin 9

This presentation begins by connecting the extant literature on formative assessment with developments in the design of assessment tools to measure teaching and learning practices that promote the development of 21st century skills including, for example, adaptive expertise, self-regulation and inquiry-based learning. The presentation then traces the design, development and trialling of the assessment for learning audit instrument (AfLAi), with specific reference to its use in gauging teachers' baseline understanding of assessment for learning (AfL) practices and the extent to which AfL is embedded in their classrooms. Following a review of the instrument's psychometric properties, data are presented that give a snapshot of the AfL practices of over 500 teachers across 40+ in Irish schools, primary and secondary. An overview is also provided of how data from individual schools have been used to inform and guide school-based professional development on assessment over time. The presentation concludes with references to the use of AfLAi internationally, to how it is being adapted for use in educational settings beyond primary and secondary schools, and to the work underway in developing complementary tools for use by students and teachers at various levels of the education system.

Teacher Education Programmes in Inquiry and Assessment across Europe

Odilla Finlayson[1], Eilish McLoughlin[1], James Lovatt[1], Deirdre McCabe[1], Paul van Kampen[1]
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The Strategies for Assessment of Inquiry-based Learning in Science (SAILS) project (2012-2015) aims to support teachers in adopting inquiry-based science education (IBSE) at second level (www.sails-project.eu). This project is focused on improving science classroom practice with students aged 12-18 years, in twelve European countries: Ireland, United Kingdom, Hungary, Belgium, Turkey, Portugal, Sweden, Germany, Denmark, Poland, Slovakia and Greece. Teachers are provided with inquiry-based teaching, learning and assessment materials supplemented with teacher education programs (Finlayson, McLoughlin & McCabe, 2015). This paper outlines how the SAILS teacher education programme was developed and implemented in three stages over the four year lifetime of the project

INTRODUCTION

There is widespread concern about the outcomes of science education in schools with too few young people selecting to study science once it is no longer compulsory in their school system. Research also suggests that the main factor determining attitudes towards school science is the quality of the educational experience provided by the teacher and so clearly, any changes to science learning in the classroom must begin with the teacher. In recent years, there has been much research and interest world-wide from educators, governments and employers on the skills and competencies needed by school leavers and graduates to succeed in life, career and citizenship. These have been termed Life-long Learning Skills and 21st century skills. These skills extend beyond the basic reading, writing and arithmetic skills to encompass such skills as critical thinking and problem solving, effective communication, collaboration, creativity and innovation, digital competence and learning to learn.

The Recommendation of the European Parliament and of the Council of 18 December 2006 on key competencies for lifelong learning (European Parliament and Council, 2006) identifies and defines eight key competences necessary for personal fulfilment, active citizenship, social inclusion and employability in a knowledge society as: Communication in the mother tongue; Communication in foreign languages; Mathematical competence and basic competences in science and technology; Digital competence; Learning to learn; Social and civic competences; Sense of initiative and entrepreneurship; Cultural awareness and expression. These have been further expanded by employers who have stated that they need a workforce fully equipped with skills beyond the basics of reading, writing and arithmetic, including: Critical thinking and problem solving; Effective communication; Collaboration; Creativity and innovation (American Management Association, 2010).

The key challenge for educationalists is to recognise these skills and to develop and implement strategies to incorporate their development in second-level and third level education (Barth, 2009). There has been a recent trend across the EU towards competence-based teaching and learning and a learning outcome approach, resulting in significant changes occurring at school curricula level in traditional subject areas such as science. These curricula are now being treated in more engaging cross-curricular ways, with greater emphasis being placed on developing skills and positive attitudes towards science alongside knowledge and with increased use of "real-life" applications to provide appealing learning contexts.

TACKLING SKILLS THROUGH INQUIRY BASED SCIENCE EDUCATION

Inquiry-based science education (IBSE) has been the focus of many national and international programs and projects in Europe in recent years as inquiry based teaching methods have been suggested as a way to encourage and motivate students in science. Additionally, it is an appropriate methodology for the development of skills and competencies in the context of science learning. According to a wide-spread understanding, the inquiry approach in science teaching is the "intentional process of diagnosing problems, critiquing experiments, and distinguishing alternatives, planning investigations, researching conjectures, searching for information, constructing models, debating with peers, and forming coherent arguments" (Linn, Davis & Bell, 2004). Thus it requires more of the learner than simply commanding and recalling scientific knowledge. Through this deeper engagement process students develop their skills sets and become more innovative and creative within their school science. The implementation of IBSE in schools has been encouraged through the European Union (e.g. Science Education NOW: A Renewed Pedagogy for the Future of Europe, 2009) which has also supported about twenty international research and development projects over the last 10 years to foster inquiry based learning (IBL). The focus of these projects was and is mainly (a) the development of teaching resources, units and materials, (b) continuous professional development (CPD) of teachers, and (c) international exchange of researchers and teachers within Europe.

To effectively implement change in classroom practice across Europe, the pedagogy of inquiry based learning has to fit in with national curricula and assessment strategies. Teachers must also be well prepared and understand the benefits of such strategies. If any curricular / pedagogical change is to be successful, the three areas of curriculum, assessment and teacher education need to be given equal prominence. Teachers need to see that the curriculum as set down at national level and also the assessment that is used are both feasible and valued using an IBSE pedagogy. For many students and teachers, assessment drives classroom activities. Most current assessment methods place a strong emphasis on knowledge recall and do not sufficiently capture the skills and attitudes dimension of key competencies. The result is that current models of assessment are typically at odds with the high-level skills, knowledge, attitudes and characteristics increasingly necessary in our fast-changing world. Furthermore, if something is assessed, then it is often more highly valued by both teachers and students.

Teacher education programmes (TEP) – both in-service and pre-service – need to be conceived so that teachers can extend their understanding of how IBSE can be used in the classroom and how the skills and competencies developed through IBSE can be assessed.

The SAILS project (www.sails-project.eu) addresses these difficulties by (a) enhancing existing IBSE teaching and learning materials by incorporating inquiry assessment strategies and frameworks; (b) partnering with teachers to identify and implement assessment strategies and frameworks to evaluate key IBSE skills and competences in the classroom; and (c) providing teacher education programmes in IBSE and promote a self-sustaining model to encourage teachers to share experiences and practice of inquiry approaches to teaching, learning and assessment - by supporting a community of practice. This project is focused on improving science classroom practice with students aged 12-18 years, in twelve European countries (Ireland, United Kingdom, Hungary, Belgium, Turkey, Portugal, Sweden, Germany, Denmark, Poland, Slovakia and Greece), by providing teachers with inquiry-based teaching, learning and assessment materials supplemented with teacher education programs (Finlayson, McLoughlin & McCabe, 2015).

This paper discusses how the teacher education programmes were developed across the twelve participating countries to promote and support teachers in inquiry based science teaching, learning and assessment.

TEACHER EDUCATION PROGRAMME (TEP) DEVELOPMENT

All SAILS partners have developed a Teacher Education Programme (TEP), with both in-service and pre-service teachers, that offers education in IBSE methodologies and also in the assessment of IBSE practices. From the beginning of the SAILS project, developing and implementing TEP was considered a core goal of the collaboration. Therefore, TEPs were started in the first year of the project – even though the assessment frameworks had not yet been prepared. The SAILS TEP have been planned to occur over three stages, with three successive cohorts of teachers, as shown in Figure 1. The focus for the first round of TEPs, with Teacher Cohort 1 (Stage 0 TEPs) was on introducing teachers to IBSE, helping teachers implement inquiry-based activities in the classroom and addressing key issues, such as classroom-management strategies, problem solving, handling investigations, etc. This cohort consisted of teachers from each country that had varying experiences in IBSE and the Stage 0 TEPs were primarily focused on the pedagogy itself and on implementing inquiry based activities in the classroom and were based on existing IBSE materials and teacher education programmes selected from those already developed from IBSE projects or from the resources already available in each country. The shared experiences of running Stage 0 TEPs informed the further development of Stage 1 TEPs.

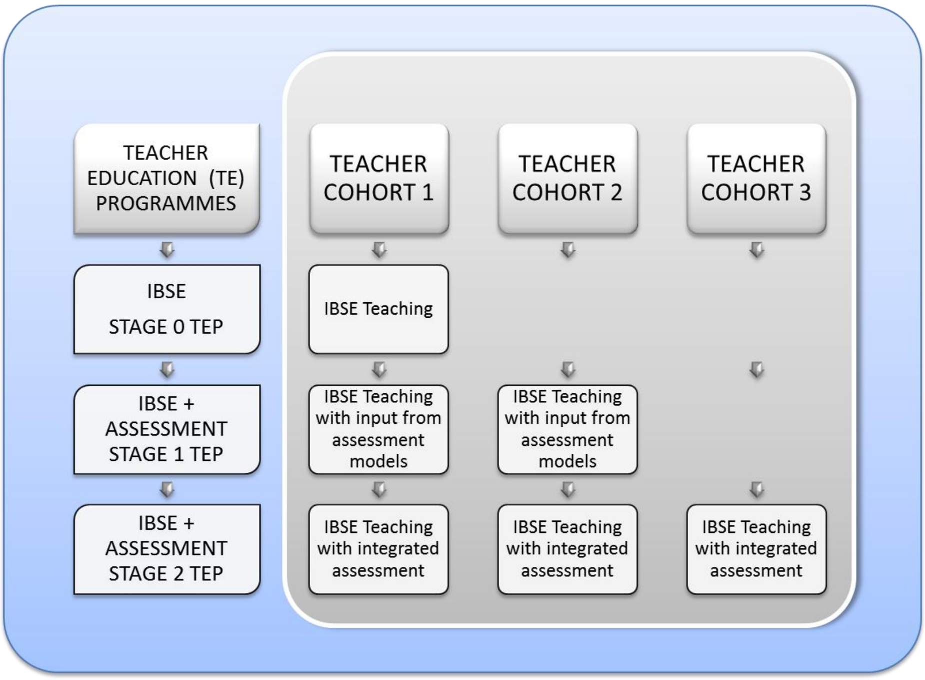

Figure 1: Overview of SAILS Teacher Education Programmes.

The second round of TEPs (Stage 1 TEPs) with Teacher Cohort 2 aimed to incorporate assessment into the inquiry programme. Several inquiry activities had been developed by SAILS partners where opportunities for assessment were highlighted throughout the activity.

Hence, Teacher Cohort 2 were involved in the TEP that now included discussion on opportunities for assessment presented through the activity and how this assessment could inform the learning occurring. Additionally, teachers from Teacher Cohort 1 were also invited back to the Stage 1 TEPs to address how assessment can be integrated with teaching and learning in an inquiry classroom.

To date, Stage 0 and Stage 1 TEPS have been implemented by each partner and the evaluation and sharing experiences of Stage 1 TEPs will inform the development of the Stage 2 TEPs that will be implemented with a new cohort of teachers (Teacher Cohort 3). The final round of TEPs (Stage 2 TEPs) aims to integrate assessment strategies within the inquiry TEPs. Additionally, Teacher Cohorts 1 & 2 will be invited to also participate in Stage 2 TEP.

Using this three-stage model for the implementation of SAILS TEPs, it was possible to facilitate appropriate workshops and activities for teachers throughout the project while further frameworks and assessment materials were undergoing development and evaluation.

Stage 0 TEP Evaluation

Following the first round of SAILS TEPs implementation, the programmes offered to teachers in all countries were evaluated and shared. Common features appeared across all the programmes and therefore were considered important to maintain/include in Stage 1 programmes.The first component in most of the teacher education programmes was to provide a discussion about scientific inquiry and the different interpretations of inquiry. Activities were provided to allow teachers to experience inquiry as a learner and teachers were provided with resources that they critiqued and discussed as to how they could implement and adapt these to meet their classroom needs. After this, teachers were encouraged to develop and trial their own inquiry lesson. The ability of teachers to develop their own resources is seen as a critical aspect of adopting an inquiry approach. In some of these Stage 1 TEPs, where teachers were already experienced in inquiry practices, workshops were focused on developing inquiry resources.

Overall, 316 in-service teachers from across ten countries participated in Stage 0 TEPs. The organisation of these programmes ranged from one-day workshops to an extended series of workshops, e.g. 10 two-hour sessions. The duration of the in-service TEPs varied from 4 hours to 33 hours. 210 Pre-service teachers across eight countries participated in Stage 0 TEPs and programmes varied from 1-day to 15-day workshops and ranged in total duration from 4.5 to 32 hours. Partners reported using IBSE resources from many of the large-scale FP7 funded IBSE projects, in addition to resources available from national projects and initiatives (e.g. ESTABLISH, PRIMAS, Fibonacci, INQUIRE, Institute of Inquiry, MONA, Physik in Kontext).

Stage 1 TEP Evaluation

STAGE 1 in-service and pre-service TEPs have been implemented across the partner countries and the exact content of these programmes has varied depending on the background of the participants: for some teachers, it was their first experience with IBSE while others were quite familiar with IBSE and also had some experience assessing inquiry skills. However some core components have been highlighted across all the TEPs.

First, the introduction and the description of IBSE was addressed. In most programmes teachers had "hands on" experience of different inquiry activities and discussed the different types of inquiry, e.g. open and guided and skills of inquiry, e.g. formulating hypothesis, planning investigations, discussion with peers. The basic strategies and tools for assessing IBSE was common to most SAILS workshops, as was the introduction of different assessment instruments for both summative and formative use. The assessment discussion focussed on the Why (i.e., formative – summative), What (i.e., content knowledge and different inquiry skills), and How (i.e., different assessment instruments, such as scoring rubrics) of assessment. In several cases a review of current literature on assessment strategies was presented and discussed.

Second, in the workshops, support was given for teachers to trial inquiry activities that incorporated assessment items and to implement these activities in their classroom. In some cases teachers had the experience of being formatively assessed while they carried out inquiry activities. This support was partly provided by their peers attending the same workshop. In this way, teachers developed their knowledge and awareness of assessment opportunities and were involved in small and whole group reflective discussions on these activities.

Third, a primary focus was to provide possibilities for teachers to design their own IBSE material and assessment instruments or to adapt existing materials to their own circumstances. The support for designing their own material was also partly provided by the peers attending the workshop. In a number of workshops the development was done in iterative cycles of feedback and revisions, either in face-to-face presentations and discussions or through the national Community of Practice.

Despite the great variation in the STAGE 1 TEPs in the participating countries and in particular the resources used, the evaluations from the teachers are unanimous in that the content and structure of the workshops were relevant and supportive. It was therefore of paramount importance that the experiences from these STAGE 1 TEPs are incorporated into the preparation of the final TEPs (Stage 2 TEPs) of the SAILS project.

IMPLICATIONS FOR STAGE 2 TEP

The SAILS Stage 2 TEPs aims to integrate education about inquiry practices with the assessment of these practices; i.e. teachers are introduced to inquiry and its assessment within the TEP. Inquiry methodologies are used to develop not only students' content knowledge, but also skills that student develop through engaging in inquiry practices such as planning investigations, argumentation, problem solving and therefore the assessment of these skills is essential to enriching and extending student learning.

From the evaluation of the Stage 1 TEPs, it is clear that a flexible TEP programme is required for several reasons as they need to:

- Accommodate the diverse range of teachers participating in such programmes- based on both subject discipline specialism, prior experience with inquiry and assessment;
- Consider the time available for in-service teachers to attend such programmes;
- Plan a suitable programme structure (summer schools/winter school vs. series of workshops over time vs. one day programmes);
- Integrate with pre-service teacher modules;
- Align with local/national cultural, societal and educational variations.

Further to the good practice highlighted in evaluation of Stage 1 TEPs, the Stage 2 programmes should also include the following essential aspects and support teachers in:

- Identifying assessment opportunities in relation to inquiry activities.
- Preparing and implementing IBSE units and assessment of inquiry skills in schools.
- Reflecting on the use of IBSE units and assessment of inquiry skills in schools.
- Designing own IBSE tasks and assessment instruments.

- Reflecting on the use of own IBSE tasks and assessment instruments.
- Considering possible gender bias within the inquiry classroom.

The importance of teachers sharing their experiences and resources with their peers, through face to face discussions and online through the national and international communities of practice is also emphasised. The benefits of peer discussion and working collaboratively are an integral aspect of IBSE and should be embodied in the approaches adopted in all TEPs and activities.

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Issues in Policy and Practice in the Assessment of Inquiry-Based Science Education

Wynne Harlen

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INTRODUCTION

The increased attention to assessment of students' achievement in the past 30 or so years, although welcome in many respects, has thrown up very many questions, challenges and matters for research (the meaning of 'issues' in this context). In this paper I first briefly raise four dilemmas facing assessment in general, before turning to questions that rise in relation to assessment in inquiry-based science education (IBSE) in particular. The four issues arise from conflicts, or disconnects, between what we would like, or ought, to be able to accomplish through assessment and what happens in practice. They are:

1. The disconnect between the aims, goals and values of education and what is currently assessed.
2. The disconnect between the aspirations of using assessment formatively and the reality of the predominance of summative uses.
3. The disconnect between the way in which we assess and what we understand about how students learn.
4. The disconnect between the narrow range of goals currently assessed and the goals of education in a global context.

Issue 1: The disconnect between the aims, goals and values of education and what is currently assessed

Assessment was once regarded as something that takes place after learning and as being quite separate from the process of learning. This view is no longer tenable; assessment is now acknowledged as a central part of education, with a proven role in helping learning as well as in reporting it. How the results of student assessment are used is recognised as having an important influence, which can be positive or negative, on the content and methods of teaching. The now well-acknowledged relationship is indicated by the equally familiar triangle in Figure 1.

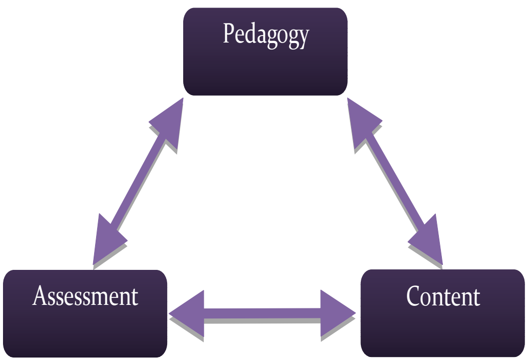

Figure 1: Interactions among curriculum content, pedagogy and assessment

The arrows acknowledge what is well known – that what we teach is influenced by how we teach, and what and how we assess influences both how and what we teach. These interactions are important for it is no use advocating the use of inquiry-based teaching if there is an overbearing assessment (whether by testing or other means) or a curriculum overcrowded with content. It is no use suggesting that the content should be focused on 'big' ideas if the assessment requires memorising multiple facts or if the pedagogy does not forge links that are necessary to form these big ideas; and it is no use wanting students to develop responsibility for their own continued learning if teaching does not allow time for reflection and room for creativity. Nor can we hope for positive attitudes towards science if the curriculum content seems to students to be remote from their interests and experience.

This does not mean that the impact of assessment on the curriculum content and teaching approach is necessarily a negative one. An effective assessment system supports learning in a variety of ways, from providing formative feedback for use in short-term decisions about learning activities to providing information about students' achievement for reporting to parents and others, for use in longer-term planning and as part of school self-evaluation. Furthermore, the process of assessment can help to clarify and communicate the meaning of learning objectives through establishing criteria for achievement or providing tasks that exemplify the use of inquiry skills and understanding.

But unfortunately negative impacts all too frequently arise. They generally result from assessment tools falling short of enabling students to show what they know and can do in relation to the learning goals. In the context of inquiry-based education it is a matter of concern that most current assessment tools and procedures fall short of what is needed to provide a good account of students' achievement of the goals of IBSE. The negative impact of this deficiency is compounded when the results for 'high stakes' evaluation of teachers and schools. When rewards and punishments are attached to assessment results this puts pressure on teachers, which is transferred to students, even when the results are not high stakes for students (as in sample surveys). Research shows that when this happens, teachers focus teaching on what is assessed, train students in how to pass tests and feel impelled to adopt teaching styles which do not match what is needed to develop real understanding. There is now a large body of research evidence on the negative impact of high stakes use of data from assessment and testing.

To engage effectively with this issue we need to develop assessment strategies and tools that better match the content and pedagogy of 21st century education. But more than this, it needs a change in policy to cease using student outcomes as the sole measure of quality of teaching or school provision for learning. One reason for this is simply that what students achieve is influenced by many factors as well as their school experiences. Another reason is that It does not provide evidence that is needed about students achievements or the quality of teaching. There has been plenty of evidence accumulated over the 25 years of experience of testing to show that year-on-year increases that appear in test scores immedately after immediately after introducing high stakes national testing are due to familiarity with test-taking and to teaching to the test (Tymms, 2004; Linn, 2000). Test scores may rise – at least at first – but this does not give information about change in real learning. The consequence of focusing on what is tested, practising test-taking and the restricted range of what is tested, is that it is not really possible to tell from national test results whether or not national standards have changed year-on-year. In other words the high stakes use of the measure defeats purpose of using it. Instead national sampling surveys, using a wide range of assessment tools, as now practised in many countries, provides a far better picture of national performance.

Issue 2. The disconnect between the aspirations of using assessment formatively and the reality of the predominance of summative uses

WE HAVE TO CONSIDER THE TWO MAIN PURPOSES OF ASSESSMENT:

- to help students while they are learning
- to find out what they have learned at a particular time.

FORMATIVE ASSESSMENT

Formative assessment has the purpose of assisting learning and for that reason is also called 'assessment for learning' (AfL). It involves processes of 'seeking and interpreting evidence for use by learners and their teachers to decide where the learners are in their learning and where they need to go and how best to get there' (Assessment Reform Group, 2002).

What is involved in formative assessment can be described in terms of an on-going cyclic process (Figure 2) in which information is gathered in relation to the students' progress towards the short-term goals of a lesson or series of lessons. This information is then used to identify the appropriate next steps for the students and the action needed to take these steps. Students, of course, are the ones who do the learning so a key feature of formative assessment is the feedback that students receive about how to improve their understanding or skills or move on. At the same time the information gathered about students' progress provides feedback to the teacher, who can then adjust the pace or challenge of the learning activities – or regulate the teaching – to maximise opportunities for learning. Students, too, can have a role in decisions about their learning and direct their efforts more effectively if they know the purpose of their activities. This means not just knowing what to do but what they are trying to achieve in terms of quality as well as goals.

In summary, the key activities that formative assessment involves are

- Students being engaged in expressing and communicating their understandings and skills through classroom dialogue, initiated by open and person-centred questions
- Students understanding the goals of their work and having a grasp of what is good quality work
- Students being involved in self-assessment so that they take part in identifying what they need to do to improve or move forward
- Feedback to students that provides advice on how to improve or move forward and avoids making comparisons with other students
- Teachers using information about on-going learning to adjust teaching so that all students have opportunity to learn.
- Dialogue between teacher and students that encourages reflection on their learning

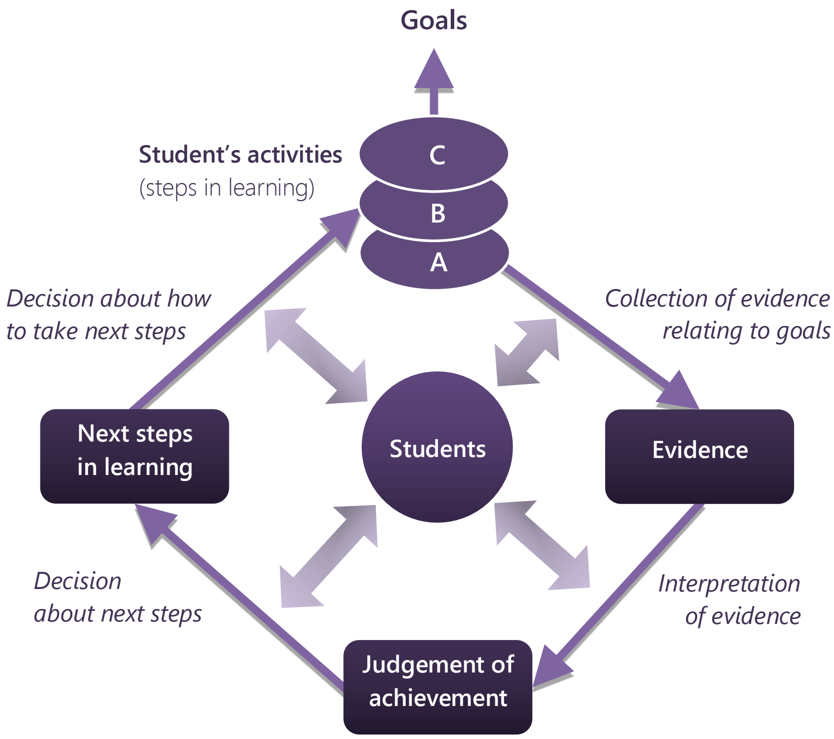

Figure 2: Assessment for formative purposes

The reason for attention to formative assessment lies in the evidence of its effectiveness in improving learning. Empirical studies of classroom assessment have been the subject of several research reviews. The review by Black and Wiliam (1998) attracted attention world-wide partly because of the attempt to quantify the impact of using formative assessment. A key finding was that 'improved formative assessment helps the (so-called) low attainers more than the rest, and so reduces the spread of attainment whilst raising it overall'. Since then there have been a number of other reviews and investigations which have justified the considerable claim made for improved student learning.

SUMMATIVE ASSESSMENT

Summative assessment has the purpose of summarising and reporting what has been learned at a particular time and for that reason is also called 'assessment of learning' (AoL). It involves processes of summing up by reviewing learning over a period of time, and/or checking-up by testing learning at a particular time.

Since formative assessment is defined as helping learning, there is tendency to regard it as the 'good' face of assessment and summative assessment as the reverse. But summative assessment is important for a number of reasons. First, whilst it is not intended to have direct impact on learning as it takes place, as does formative assessment, it nevertheless can be used to help learning in a less direct but necessary way as, for example, in providing a summary of students' learning to inform their next teacher when students move from one class or school to another. Second, it enables teachers, parents and schools to keep track of students' learning, both as individuals and as members of certain groups (such as those who are high achievers and those who need special help). Third, it provides data which, together with contextual factors, can be used for school evaluation and improvement. Finally, it cannot be avoided: teachers have little choice about whether and when they conduct summative assessment since requirements and procedures are generally established at school or national level, not by individual teachers. By contrast, formative assessment could be considered, in a sense, to be voluntary in that it is possible to teach without it and it is part of the process of teaching, which teachers largely decide for themselves. Formative assessment can be urged in official documents but cannot be mandated in the way that summative assessment can be required by statute.

One reason for the poor reputation of summative assessment is that when measured performance becomes the dominant factor in the classroom it drives out formative assessment practice. Pollard *et al*. (2000) noted that the introduction of national tests in England in the 1990s and the requirement for teachers to assign levels to students affected their response to students and their use of formative assessment. Students were aware that whilst effort was encouraged, it was achievement on tests that counted. The same is found for older students right up to undergraduate level; student want to know ''is it for the examination?" to decide whether to give it their effort. Where there is competition between formative and summative assessment, the latter will always come out as the winner.

An obvious solution to this issue is to avoid competition by bringing the two together. The two ways of doing this are to make use of formative assessment data for summative purposes or to make formative use of summative assessment. Since formative assessment is carried out by teachers (and students), the first of these means using teachers' judgments for summative assessment. In relation to the second case – of using summative assessment formatively, several ways of using classroom tests and internal school examinations to feed back into teaching and learning have been suggested (Black *et al.*, 2003)˙ In practice the approach is one that teachers can use principally in the context of classroom tests over which they have complete control. Whilst some external tests and examinations can be used in this way, by obtaining marked scripts and discussing them with students, there is a danger that the process can move from developing understanding to 'teaching to the test' and in any case the feedback comes too late.

An example of combining formative and summative purpose in assessment that has high stakes for students is the approach used for many years in the Queensland Certificate of Education in Australia, used in determining entry to high education. In the Queensland system of externally moderated school-based assessment, teachers develop and implement assessment programs and instruments that cater for their school's unique context, resources and students. The overall approach is the development of a portfolio of evidence from assessment tasks set by the teacher to meet the requirements of the syllabus for each subject. The portfolio allows a variation in the content so that syllabuses can be implemented with flexibility to meet local requirements. The common element is the system of progressive criteria, called Standard Descriptors, against which each portfolio is judged. The portfolio is built up over the two years of the course, during which time its content will change not only through addition of new material but through replacing older by more recent evidence. It is only the final evidence that is taken into account, although some will have been collected earlier than other. The criteria for assessment are published so that students and parents as well as teachers can be familiar with them. They describe what students can do in various categories and sub-categories at five levels or standards. Evidence from the portfolio is compared with the criteria using 'on-balance' judgements of best fit.

Issue 3. The disconnect between the way in which we assess and what we understand about how students learn

The discussion in relation to Issue 2 focused mainly on the curriculum content. This issue relates more to pedagogy and the alignment between the contexts and processes of learning and of assessment. To explain why we need to bring learning theories into the discussion of assessment, consider the three main theories and their simple formulation (Watkins, 2003):

- Behaviourism: "Learning is being taught"
- Cognitive constructivism: "Learning is individual sense-making"
- Socio-cultural constructivism: "Learning is building knowledge as part of doing things with others."

Behaviourism describes a view of learning in which behaviours are formed by a system of rewards and punishments, so learning can be controlled externally and motivation is almost entirely extrinsic. A feature particularly relevant to assessment is that complex behaviours are deconstructed into parts which can be taught, practised and assessed separately. This view, then, is consistent with tests of disconnected facts and skills, where speed is of the essence and answers are either correct or incorrect.

Cognitive constructivism views learning as constructed by learners themselves and influenced by their existing knowledge. The aim is understanding, which is seen as occurring when new experience is incorporated into an existing or new model. The active participation of students is seen as paramount because, as widely quoted, 'they do the learning'. Constructivist views of learning underpin formative assessment, but there are few examples of summative assessment being based on a constructivist view of learning, although there are some attempts through computer adaptive testing and screen-based concept-mapping (Osmundson *et al.*, 1999).

In *socio-cultural constructivist* perspectives on learning there is also a focus on understanding but through 'making sense of new experience with others' rather than by working individually. In these situations the individual takes from (internalises) a shared experience what is needed to help his or her understanding, then externalises the result as an input into the group discussion. There is a constant to-ing and fro-ing from individual to group as knowledge is constructed communally through social interaction and dialogue. Modern views of science education reflect this approach, emphasising inquiry, thinking scientifically, building models, engaging in argumentation and critical reflection, through working in groups, sharing ideas communicating in a variety of modes. Clearly there is little in common between this view of learning and what is represented in traditional modes of assessment where students sit in isolation from one another in an examination room.

Some profound implications for assessment also follow from the view proposed by Vygotsky (1978) that for any learner there is an area just beyond current understanding where more advanced ideas can be used with help. Vygotsky called this area the 'zone of proximal (or potential) development'. It is, in essence, what we have called the 'next step' that the student can be expected to take identified through formative assessment. 'Scaffolding' is an apt term used to describe helping students to take this next step in understanding through introducing new ideas or better scientific practices and providing vocabulary that enables students to express their ideas more precisely.

Recognising that, in the company of other learners, students can exceed what they can understand and do alone, throws into doubt what is their 'true' level of performance. Is it the level of 'independent performance' or the level of 'assisted performance' in the social context? It has been argued that the level of performance when responding to assistance and the new ways of thinking provided by others gives a better assessment than administering tests of unassisted performance (Grigorenko, 1998).

Research conducted in Denmark (Dolin and Krogh, 2010) using items from the PISA science tests provides clear support for this view. The research involved students in answering some PISA questions orally in an interview and conducting, in pairs, an investigation described in a PISA item. The conclusion reached was that 'when compared directly and following the scoring criteria of PISA, pupils' performance increased by 25% when they were allowed to exercise their knowledge in a socio-culturally oriented test format.'

Issue 4. The disconnect between the narrow range of goals currently assessed and the goals of education in a global context.

Issue 3 has taken the critique of assessment beyond concern with content. Issue 4 takes it further into matters that concern its contribution to goals of education that encompass major global issues: for example, the adverse impacts climate change and global warning on hunger, ill health, illiteracy, unemployment, etc. The question is: do we, can we, make any contribution to understanding and alleviating these conditions in the way we go about science education and its assessment? In one sense this seems a ridiculous question, like asking whether by eating less we can help the millions who go hungry across the world. But if we answer that we can do nothing, then what will ever change?

Education has a key role, particularly in developing students and future citizens who are thoughtful, in every sense, and understand the role of human activity in global warming, loss of diversity of organisms that lead to starvation, poverty, lack of education and unemployment. So we ought to be able through science education to make a contribution by helping understanding of the ideas that are relevant and powerful in making sense of the world and how it works, how its components interact, how human intervention can and cannot influence our global environment. This means identifying the 'big' ideas *of* science and *about* science (that is, how science operates, its strengths and limitations) (Harlen, 2010) and ensuring that science education is designed to develop understanding of these ideas.

So where does assessment come into the picture? In brief, it is through ensuring that all assessment helps learning. This means using assessment formatively to regulate teaching and learning to support understanding. It also means using summative assessment to support learning through better understanding of the goals and what it means to achieve them and monitoring the progress of students towards the powerful ideas and scientific inquiry skills. Assessment, then, needs to be part of the discussion of how to provide education of relevance to facing global problems.

CHALLENGES FOR IBSE

The goals of IBSE

These issues have wide relevance in educational assessment. To anchor the discussion to the context of inquiry-based science education (IBSE) we need to be sure of goals to be assessed. It is difficult to put together in a single statement the interacting components of the process of learning through inquiry, which is why there are several definitions. It is easier to show how understanding is built through collecting and using evidence to test possible explanations through a diagram, as in Figure 3.

> In inquiry-based learning the development of understanding stems from curiosity about a phenomenon or event (a) that is new to the learners and raises questions that grab their

attention. Initial exploration may reveal features that bring to mind an idea from previous experience which suggests a possible explanation or an answer to a question (b). It may be the idea of an individual student or the result of brain-storming with other students or consulting sources of information. Working scientifically involves making a prediction based on the idea (c) and then gathering relevant data (d) to see if there is evidence to support the prediction and the application of the idea (e). This might be a lengthy investigation involving controlled experimentation or just a simple extension of observations.

Finding that evidence fits with the prediction (f) and that the idea does provide a good explanation (b) means that this idea has become 'bigger' since it then explains a wider range of phenomena. Even if it does not seem to 'work', something has been learned about its range of application. But to find an explanation that does 'work' means that alternative ideas have to be used and tested. This may come from the initial or further brain-storming informed by what has then been found. The usefulness of the ideas developed in this way depends on the collection and use of evidence in a scientific manner. Thus the ability to use science inquiry skills is an essential part of the development of understanding and an outcome of shared thinking about what data to collect and how to go about collecting and interpreting them.

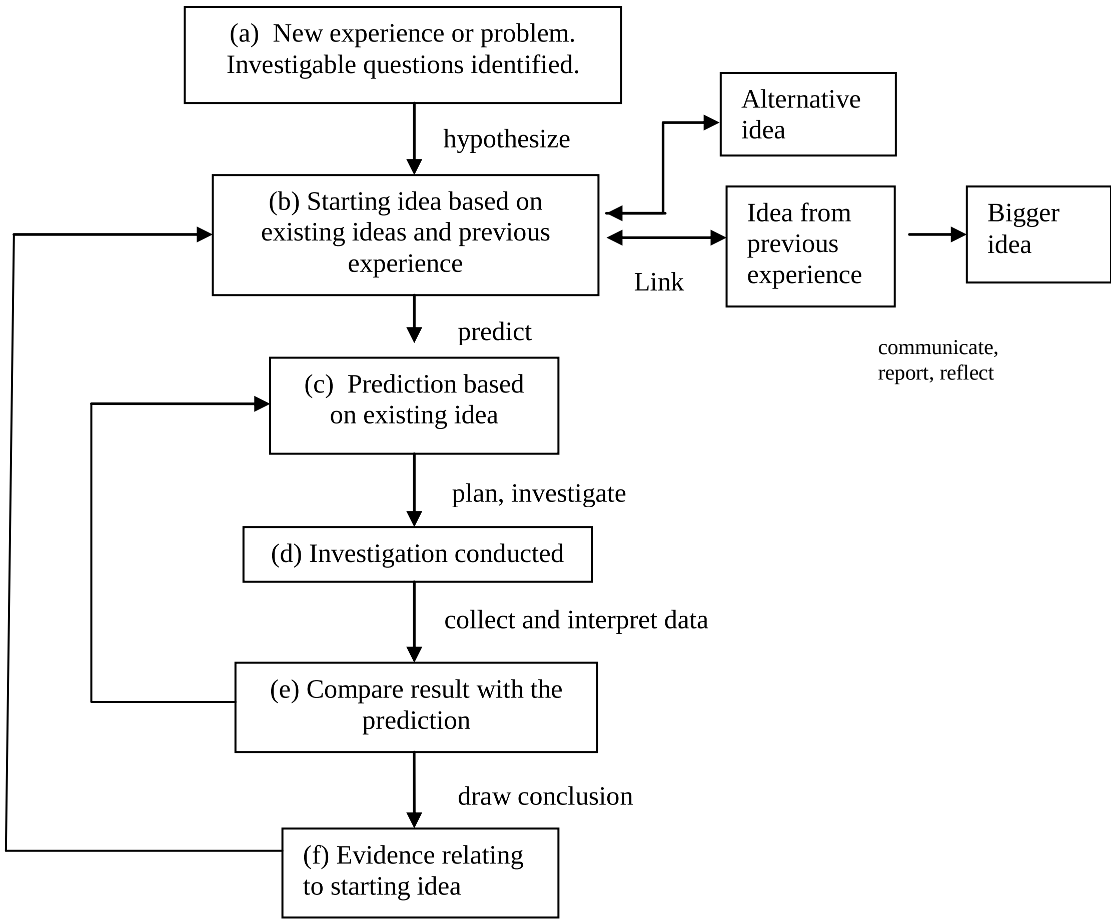

Figure 3: A model of learning through inquiry. Based on Harlen and Qualter (2013).

This description of inquiry does not restrict it to practical activity. Often the evidence that is needed will come from secondary sources rather than direct contact with or experimentation with materials. This challenges the assumption that inquiry must mean ‘hands on’ or ‘practical work’. Another misconception, which is important in relation to assessment is that the aim of inquiry-based work is chiefly to develop the ability to ‘behave as a scientist’ and learn about a supposed ‘scientific method’. There are two problems here. One concerns the goals of inquiry-based education in science. Placing the emphasis on processes of inquiry has led some to the mistaken view that inquiry is more appropriate in the primary school than in secondary education. Whilst it is important for students to know how scientific knowledge is created, their learning must help students at all levels to develop ideas that help them to understand in the world around, the ideas of science, as well as ideas about science. The other problem is the assumption of a single scientific method. In studying different aspects of the world, such as cosmology or ecology, scientists work in different ways. There is no single formula for scientific activity and certainly none that includes mathematics and science and thus no single approach to inquiry-based education.

IMPLICATIONS FOR ASSESSMENT OF IBSE

The discussion of formation assessment (figure 2) shows that it is essential to the implementation of IBSE. It involves skills and knowledge in accessing students’ on-going learning through questioning, classroom dialogue and observation. But the greatest challenge is in using this information to decide, and then take, any action needed to help progress towards learning goals. This requires knowledge and understanding of development in students’ conceptual and procedural learning. Many teachers need help with this part of formative assessment.

However, the influence that summative can have on formative assessment clearly means that giving attention to formative assessment alone would be likely to have little effect. Indeed the experience of introducing genuine formative assessment in countries where there exists a strong dependence on external high stakes tests, bears evidence to this. Thus if learning in science is to be improved through IBSE and the use of formative assessment, it is necessary also to ensure that the summative assessment is consistent with the learning aims of IBSE.

It is the dual nature of the goals of IBSE, the combination of conceptual understanding and skills that presents one of the greatest challenge to summative assessment. It means that both understanding and skills need to be assessed and raises the question of whether these can, and should, be assessed separately or in combination. Indeed it can be argued that it is not possible to assess understanding without some skills being used and vice versa. The assessment of understanding of a concept the assessment task should require an explanation of an event or interpretation of data or a prediction involving application of some concepts. Thus there are some skills (explaining, interpreting, predicting) that are also involved. For assessing skills, the task has to require the use one or more of the inquiry skills, such as predicting, planning, carrying out an investigation or interpreting given data. However, it is not possible to assess skills without involving some knowledge of the subject matter of its use. (Using trivial, non-scientific content raises the question of whether a skill is a science inquiry skill if it is not used in relation to science subject matter). Thus there will always be some aspects of understanding and skill required in all tasks. What determines whether a task is essentially assessing understanding or skill will be the level of demand on one or the other, and the credit given to different kinds of responses in scoring.

A further factor to be considered is that for valid assessment students need to be working on tasks where some aspects of inquiry are involved. There should also be some novelty in the task so that they are using their knowledge or skill and not simply recall of information, reasons or procedures that have been committed to memory. Genuine inquiry takes place when students seek to answer a question that is new to them and to which they do not already know the answer. But who is to judge what is 'new' for a particular student? Can the response of a student created in isolation from the normal context of learning and interaction with others really reflect their capability? These are questions which apply to any assessment conducted through tests or examinations but particularly to IBSE.

The alternatives to tests depend on the fact that the experiences that students need in order to develop desired skills, understanding and attitudes also provide opportunities for their progress to be assessed. The key factor is judgement by the teacher. Assessment by teachers can use evidence from regular activities supplemented, if necessary, by evidence from specially devised tasks introduced to provide opportunities for students to use the skills and understanding to be assessed. Such approaches have to include effective quality management procedures that assure acceptable levels of reliability and consistency across schools. Key conditions for such an approach are time for teachers to take part in moderation to ensure dependability of the results and respect for teachers' professionalism. Time spent in this way, however, is a valuable form of professional development in assessment. Experience in Queensland, for example, is that 'The most powerful means for developing professional competence is assessment is the establishment of regular professional conversations among teachers about student performance (Maxwell, 2004).'

Other alternatives affording opportunities for more valid assessment of the outcomes of learning through inquiry may emerge from developments in screen-based assessment, but are yet at an early stage. Promising research into relevant assessment methods is being conducted by the ASSIST-ME (2014) project (an EU FP7 project) involving 10 partners in 8 countries.

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Designing Formative Assessment in Mathematics

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Formative assessment is the process by which students and teachers gather evidence of learning and then use it to adapt the way they learn and teach in the classroom. In this paper I describe a design research project in which we are attempting to develop and integrate "formative assessment lessons" into classrooms across the US. In this paper, I focus on some of the issues that arose as we attempted to design lessons that would develop students' capacity to tackle non-routine problems. Particular formative aspects of lesson design are highlighted; the important roles of pre-assessment, formative feedback questions and sample work for students to critique are described.

INTRODUCTION

The potential power of formative assessment for enhancing learning in mathematics classrooms was brought to widespread attention by the research review of Paul Black and Dylan Wiliam (Black, et al. 2003; 1998; Black, et al. 1999). They launched programs of work that aimed to turn these insights into impact on practice, but found that regular meetings over a period of years were needed to enable a substantial proportion of teachers to acquire and deploy the "adaptive expertise" (Hatano & Inagaki 1986; Swan 2006a) needed for self-directed formative assessment. This is clearly an approach that is difficult to implement on a large scale. Since their research was published, the term "formative assessment" has entered common parlance where it has often been mutated to mean more frequent testing, scoring and record keeping. This, however, corrupts Black and Wiliam's original use of the term where it is taken to include:

> "… all those activities undertaken by teachers, and by their students in assessing themselves, which provide information to be used as feedback to modify the teaching and learning activities in which they are engaged. Such assessment becomes 'formative assessment' when the evidence is actually used to adapt the teaching work to meet the needs." (Black & Wiliam, 1998, p91)

Here lies the challenge: for assessment to be truly formative the teacher must develop expertise in becoming aware of and adapting to the specific learning needs of students, both in planning lessons and moment-by-moment in the classroom.

In 2009, the Bill & Melinda Gates Foundation approached us to develop a suite of formative assessment lessons to form a key element in the Foundation's program for "College and Career Ready Mathematics" based on the Common Core State Standards for Mathematics (NGA & CCSSO 2010). In response, the Mathematics Assessment Project (MAP) was designed to explore how far well-designed teaching materials can enable teachers to make high-quality formative assessment an integral part of the implemented curriculum in their classrooms, even where linked professional development support is limited or non-existent. The research-based design of these lessons, now called *Classroom Challenges,* forms the core of this paper. To date, we have designed and developed over one hundred formative assessment lessons to support US Middle and High Schools in implementing the new

Common Core State Standards for Mathematics. Each lesson consists of student resources and an extensive teacher guide. About one-third of these lessons involve the tackling of non-routine, problem-solving tasks. They are available on the website: http://map.mathshell.org.uk/materials/index.php.

METHODOLOGY

Our methodology is based on design research principles, involving theory-driven iterative cycles of design, enactment, analysis and redesign (Barab & Squire 2004; Bereiter 2002; Cobb, et al. 2003; DBRC 2003, p. 5; Kelly 2003; van den Akker, et al. 2006). Each lesson was developed, through three iterative design cycles, with each lesson being trialled in three or four US classrooms between each revision. Revisions were based on structured, detailed feedback from experienced observers of the materials in use in classrooms. We thus have over 700 observer reports of lessons using these materials.

The objective of these trials was to give the design team a detailed picture of what happened in the use of the materials by teachers. The aim is to learn more on questions including:

- Do the teacher and students understand the materials?
- How closely does the teacher follow the lesson plan?
- Are any of the variations damaging to the purpose of the lesson?
- What features of the lesson proved awkward for the teacher or the students?
- What unanticipated opportunities arose that might be included on revision?

This process enabled us to obtain rich, detailed feedback, while also allowing us to distinguish general implementation issues from idiosyncratic variations by individual teachers.

THEORETICAL BACKGROUND

The theories that have underpinned our designs go back to our "Diagnostic Teaching" program of design research in the 1980s. This was an example of formative assessment of the kind identified as effective by Black and Wiliam (See e.g. Bell 1993; Swan 2006a). This approach to teaching mathematical concepts was more effective, over the longer term, than either expository or guided discovery approaches. This result was replicated over many different topics: decimal place value, rates, geometric reflections, functions and graphs, and fractions (Bassford 1988; Birks 1987; Brekke 1987; Onslow 1986; Swan 1983). From these studies it was deduced that the value of diagnostic teaching appeared to lie in the extent to which it valued the intuitive methods and ideas that students brought to each lesson, offered experiences that created inter- and intra-personal 'conflicts' of ideas, and created opportunities for students to reflect on and examine inconsistencies in their interpretations. A phase of 'preparing the ground' was found necessary, where pre-existing conceptual structures were identified and examined by students for viability. The 'resolution' phase, involved students in intensive, reflective discussions. Indications were that the greater the intensity of the discussion, the greater was the impact on learning.

More recently, these results have been replicated on a wider scale. UK government funded the development of a multimedia professional development resource to support diagnostic teaching of algebra (Swan & Green 2002). This was distributed to all FE colleges, leading to research on the effects of implementing collaborative approaches to learning in 40 GCSE retake classes. This again showed the greater effectiveness of approaches that elicit and address conceptual difficulties through student-student and whole class discussion (Swan 2006a, 2006b; Swan 2006c). The government, recognizing the potential of such resources, commissioned the design of a more substantial multimedia PD resource, 'Improving Learning in Mathematics' (DfES 2005). This material was trialled in 90 colleges, before being distributed to all English FE colleges and secondary schools.

In our design of lessons for problem solving we have also drawn inspiration from the Lesson Study research in Japan and the US (Fernandez & Yoshida 2004; Shimizu 1999). In Japanese classrooms, lessons are often structured with four key components: *hatsumon* (the teacher gives the class a problem to initiate discussion); *kikan-shido* (the students tackle the problem in groups or individually); *neriage* (a whole class discussion in which alternative strategies are compared and contrasted and in which consensus is sought) and finally the *matome*, or summary. Among these, the *neriage* stage is considered to be the most crucial. This term, in Japanese refers to kneading or polishing in pottery, where different colours of clay are blended together. This serves as a metaphor for the considering and blending of students' own approaches to solving a mathematics problem. It involves great skill on the part of the teacher, as she must select student work carefully during the *kikan-shido* phase and sequence the work in a way that will elicit the most profitable discussions. In the *matome* stage of the lesson, the Japanese teachers will tend to make a careful final comment on the mathematical sophistication of the approaches used. The process is described by Shimizu:

> "Based on the teacher's observations during Kikan-shido, he or she carefully calls on students to present their solution methods on the chalkboard, selecting the students in a particular order. The order is quite important both for encouraging those students who found naive methods and for showing students' ideas in relation to the mathematical connections among them. In some cases, even an incorrect method or error may be presented if the teacher thinks this would be beneficial to the class. Once students' ideas are presented on the chalkboard, they are compared and contrasted orally. The teacher's role is not to point out the best solution but to guide the discussion toward an integrated idea."
>
> (Shimizu 1999, p110)

In part, perhaps, influenced by the Japanese approaches, other researchers have also adopted similar models for structuring classroom activity. They too emphasise the importance of: anticipating student responses to cognitively demanding tasks; careful monitoring of student work; discerning the mathematical value of alternative approaches in order to scaffold learning; purposefully selecting solution-methods for whole class discussion; orchestrating this discussion to build on the collective sense-making of students by intentionally ordering the work to be shared; helping students make connections between and among different approaches and looking for generalizations; and recognizing and valuing and students' constructed solutions by comparing this with existing valued knowledge, so that they may be transformed into reusable knowledge (Brousseau 1997; Chazan & Ball 1999; Lampert 2001; Stein, et al. 2008).

Each of these aspects presents a substantial challenge for teachers in a problem-solving context. Normally in the course of teaching mathematical skills, student reasoning is predictable and short. When problem solving, students construct chains of reasoning that may not be well-expressed nor easily predicted. In the busy classroom, teachers have little time to spend listening over the shoulders of students as they discuss alternative problem solving strategies. Often students' sharing of their methods in whole class discussions are reduced to mere 'show and tell' occasions and do not reveal the thinking behind the approaches in any depth. Frequently, students' presentations are poorly expressed and remain incomprehensible to their peers and teachers appear more concerned with giving everyone a chance to share than in analysing the quality of the reasoning. Merely accepting answers, without attempting to critique and synthesise individual contributions can constrain the development of mathematical thinking (Mercer 1995).

THE DESIGN OF THE CLASSROOM CHALLENGES

We now illustrate how this research has informed the products of our design research using one of the Classroom Challenges, focused on problem-solving: "Counting Trees" (Figure 6). Further lessons may be downloaded from http://map.mathshell.org.

Counting Trees

The diagram shows some trees in a tree farm.

The circles ● show old trees and the triangles ♦ show young trees.

Tom wants to know how many trees there are of each type, but says it would take too long counting them all, one by one.

1. What method could Tom use to estimate the number of trees of each type?
2. Use your method to estimate the number of:
   (a) Old trees (b) New trees.

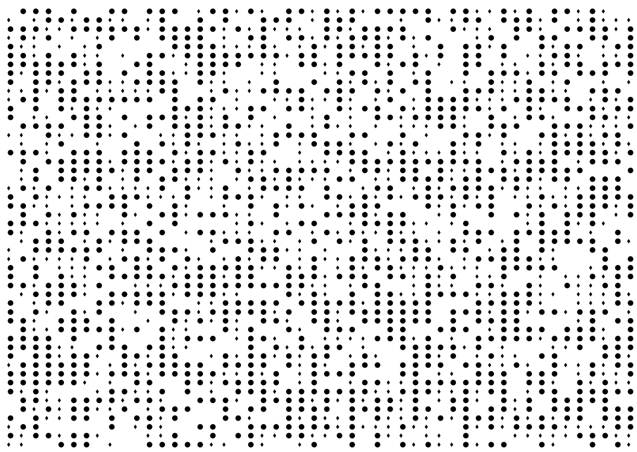

Figure 1: The "Counting trees" task

As a preliminary assessment, students are invited to tackle a problem individually. This exposes students' different approaches. Through trialling, we have developed a "common issues table" that lists for the teacher the most common difficulties that students have together with suggestions for questions that the teacher might pose to move thinking forward (Table 1). The teacher guide suggests that students' responses are collected in by the teacher and analysed, with the help of this table. The teacher may, if time permits, write some of these questions on each student's work, or alternatively prepare a few questions for the whole class to consider. This process has enabled teachers to anticipate student reasoning in the main lesson.

Table 1: A few of the common issues and suggested questions for "Counting Trees"

Common issues	Suggested questions and prompts
Student chooses a method which does not involve any sampling: E.g. student counts the trees.	• Have you done what was asked? • What assumptions have you made? Are your assumptions reasonable?
Student chooses a sampling method that is unrepresentative. E.g.: student counts trees in the first row and multiples by the number of rows.	• How could you improve/check your estimate? • Is your sample typical of the whole tree farm? How do you know?
Student makes incorrect assumptions. E.g.: student does not account for gaps.	• Is there a pattern to how the trees are distributed in the tree farm? Does your work assume there is a pattern? • What does your method assume? Is this a reasonable assumption?
Student chooses appropriate sampling method	• Can you suggest a second, different sampling method? • If you miscount your sample by 1, how does that affect your overall estimate?

The lesson itself begins with the teacher returning students' initial individual attempts along with the prepared questions. Working individually, students review their initial attempts and try to respond to the teacher's questions.

The students are now asked to work in small groups to discuss the work of each individual, then to produce a poster showing a joint solution that is better than the initial attempts. Groups are often organized so that students with contrasting ideas are paired. This activity promotes peer assessment and refinement of ideas. The teacher's role is to observe the groups and challenge students to justify their decisions as they progress and thus refine and improve their strategies.

The teacher now introduces up to four pieces of "sample student work", provided in the materials (Figure 2). This pre-prepared work has been carefully chosen to highlight alternative approaches and common mistakes. Each piece of work is annotated with questions that focus students' attention. So, for example: *Does Laura's approach make mathematical sense? Why does she halve her answer? What assumptions has Laura made? How can Laura improve her work? To help you understand Laura's work, what question(s) would you ask her?* Introducing work from outside the classroom is helpful in that (i) students are able to critique it freely without fear of other students being hurt by criticism; (ii) handwritten 'student' work carries less status than printed or teacher-produced work and it is thus easier for students to challenge, extend and adapt. A further benefit is that this work enables teachers to prepare the discussion before the lesson, avoiding the difficulty of having to select work from the class during the lesson itself.

We have found that teachers like to be flexible in the way they distribute sample student work, in response to the particular needs of their own students. For example if students have struggled with a particular strategy, the teacher may want them to analyse a similar sample student work. Conversely if students successfully solved the problem using a particular strategy, then the teacher may want to them to analyse sample student work that uses a different strategy. The teacher can thus decide if their students would benefit from working with all the sample student work or just one or two pieces.

Laura attempts to estimate the number of old and new trees by multiplying the number along each side of the whole diagram and then halving. She does not account for gaps nor does she realize that there are an unequal number of trees of each kind.

Can you explain why Laura halves her answer? What assumption is she making?

Amber chooses a representative sample and carries through her work to get a reasonable answer. She correctly uses proportional reasoning. She checks her work as she goes along by counting the gaps in the trees. Her work is clear and easy to follow, although a bit inefficient.

Can you explain why Amber multiplies by 25 in her method?

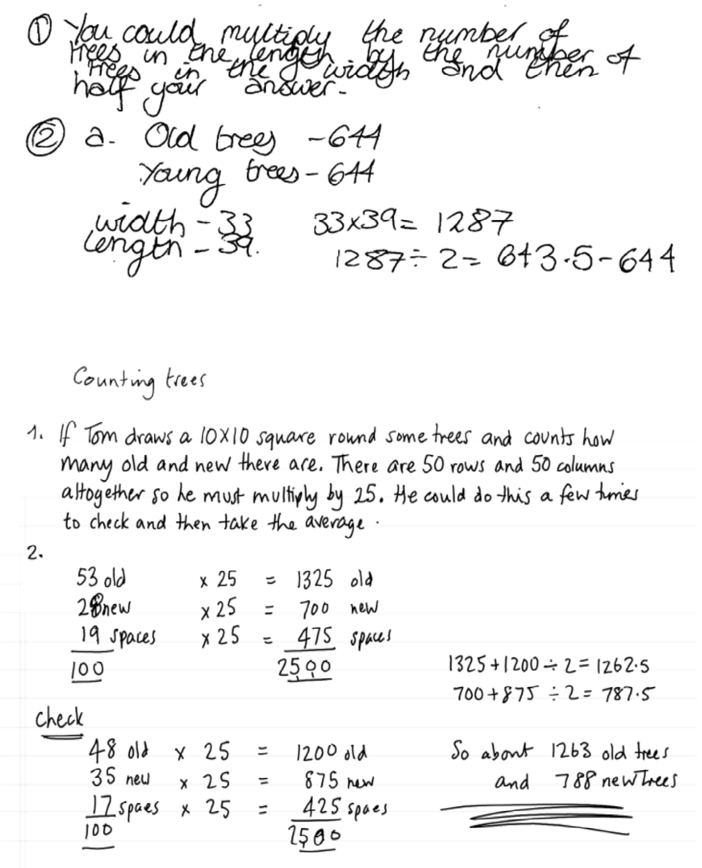

Figure 2: Sample student work for discussion, with commentary from the teacher guide.

After critiquing the sample work, students are encouraged to revise their own group solutions. This process of successive refinement in which methods are tried, critiqued and adapted has been found to be extremely profitable for developing problem solving strategies.

The lesson concludes with a whole class discussion that is intended to draw out some comparisons of the approaches used; in this case the power of sampling. Students are invited to respond individually to such questions as:

- How was your group's solution better than your individual solution?
- How did you check your method?
- How was your response similar to or different from the sample student responses?
- What assumptions did you make?

CONCLUDING REMARKS

In this brief paper, I have attempted to describe how systematic design research has enabled us to tackle a significant pedagogical problem: how might we enable students to develop the skills necessary for the effective tackling of non-routine problems. This involves the development of planning, monitoring and critiquing behaviours on the part of students;

aspects that are not developed in mathematics lessons that focus on routine skills. Particular features that we have found of importance are:

- **Pre-assessment**; giving students opportunity to engage with the problem individually, before group discussion takes place and giving the teacher opportunity to anticipate student reasoning in advance of the lesson;
- **Common issues tables**; that use empirical research results to inform teachers of the likely issues that students will face in the lesson and offer teachers suggested formative questions that they may ask students during the lesson;
- **Sample student work** that focuses student attention on the comparison of alternative approaches, assumptions made, representations used and offers them opportunity to develop criticality. In addition this allows the teacher to plan discussions of such strategies before the lesson.

We have found that, as might be expected, the *neriage* and *matome* stages of the lesson in which teachers select, synthesise and generalise what has been achieved in the lesson are still the most challenging and these aspects are currently being researched in a new Lesson Study Project on problem solving funded by the Nuffield Foundation.

The resulting lesson plans we have developed are extensive (for counting trees it covers seven pages), reflecting the new territory that many teachers find themselves. This has been in response to teacher requests for advice and guidance. The result has have proved very popular with teachers (to date, over two million of the lesson plans have been downloaded). To quote one of the trial teachers:

> "At my school kids have generally not been interested in mathematics. They haven't seen it as exciting, as a chance to think critically, and as a fun challenge. But I think Classroom Challenges change that. The CCs offer the right portrayal of what mathematics is about. When kids begin to experience that they see how rich and how exciting the subject really is."

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ESTABLISH - a model for widespread implementation of inquiry based science education

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The ESTABLISH project (2010-2014) (www.establish-fp7.eu) was funded under the EU FP7 programme as a pan-European approach to implementing innovation in second level science classroom practice. This has been achieved through the provision of appropriate teaching and learning resources and supports for both in-service and pre-service teachers to implement inquiry based science education (IBSE) in 11 countries across Europe (Ireland, Germany, Sweden, Cyprus, Czech Republic, Poland, Slovakia, Malta, Netherlands, Estonia and Italy). The ESTABLISH collaboration have developed teaching and learning materials that have been piloted and trialed in the classrooms of Europe and that can be a central focus of teacher education programmes in inquiry. The ESTABLISH consortium have provided teacher education programmes in inquiry practices to 2090 teachers across Europe, focused at the teaching and learning of science (Physics, Chemistry and Biology) at both lower and upper secondary level. This paper summarises the symposium delivered at SMEC where three main aspects of the ESTABLISH project were considered, namely: the approach of stakeholder involvement, the framework for and development of inquiry materials, the education of teachers using these authentic learning resources.

INTRODUCTION

The recent trend across the EU towards competence-based teaching and learning and a learning outcome approach (Commission of the European Communities (CEC) 2009), has resulted in significant changes occurring at school curricula level in traditional subject areas such as science. These curricula are now being treated in more engaging cross-curricular ways, with greater emphasis being placed on developing skills and positive attitudes towards science in tandem with the development and transfer of content knowledge, e.g. through increased use of "real-life" applications to provide appealing learning contexts. Many of today's employers, however, have highlighted that "…high school graduates were 'deficient' in skills such as problem solving and critical thinking" (Barth, 2009), pointing to a mis-match between the skills that educational systems supply and the skills that employers desire.

Crucial to the development of these key competencies in young people is their engagement in the education process. Methodologies such as inquiry-based science education (IBSE) have been highlighted as having the potential to increase student engagement in science at primary and second level and provide such development opportunities (Osbourne & Dillon, 2008; Fensham, 1986; Linn et al., 2006; European Commission (EC), High Level Group on Science Education, 2007). Recommendations from these international reports identify the need for "engaging curricula to tackle the issue of out-of date and irrelevant contexts and to enable teachers to develop their knowledge and pedagogical skills". This reform of science education on a global scale by encouraging hands-on inquiry-based learning, especially in primary and second level schools, is also encouraged by the global network of science academies (ALLEA Working Group Science Education, 2012) where they define IBSE as comprising of "experiences that enable students to develop an understanding about the scientific aspects of the world around them through the development and use of inquiry skills" (Harlen & Allende, 2006).

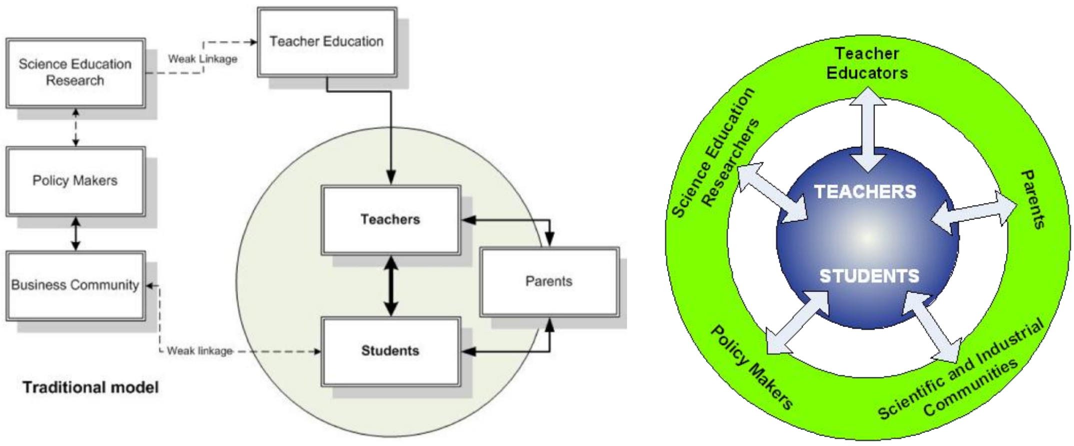
The European Commission have supported Inquiry-Based Science Education (IBSE) as a suitable methodology to implement in classrooms across Europe to engage young people in science and mathematics and to develop skills and competencies to cope with the challenges for a changing world. Several large scale projects have been funded through the Seventh Framework Programme (FP7) to support and coordinate actions on innovative methods in science education through teacher education in IBSE. ESTABLISH is one such FP7-funded project which brings together a pan-European consortium from across 11 participating countries to disseminate and increase the use of IBSE across Europe (www.establish-fp7.eu). A specific focus of ESTABLISH was to promote innovation in classroom practice by bringing together and involving all the key communities in second level science education and also by developing and making available authentic inquiry materials and resources. This paper will summarise the symposium offered at SMEC, highlighting the three main aspects of the project, namely: the approach of stakeholder involvement, the framework for and development of inquiry materials, the education of teachers using these authentic learning resources.

ESTABLISH PROJECT DESIGN AND APPROACH

The specific aim of ESTABLISH was to bring together and involve key communities in second level science education to implement inquiry based science education in the classroom. These key communities, the stakeholders of science education, include science teachers and educators, the scientific and industrial communities, young people and their parents, the policy makers and the science education research community. Each of these have a role to play in second level science education, with some having a more direct impact on performance, some on policy, and others on the 'doing' of science at second level. The relationship between these communities is quite complex given the unequal strength of each relationship. There are many societal demands placed on science education which may or may not be complementary. Fensham (Fensham, 1991) characterises science education as offering the realisation of the potential to meet the demands of its learners for individual growth and satisfaction. Teachers want their students to do 'well', while industry needs employees with an ability to innovate, and policymakers want the economy to grow. Thus there is a shift in emphasis from the micro level (the student) to the macro level (the economy) and it is often assumed that there is a direct thread running between these levels. However, many other communities need to actively share and understand the common goals and the methodologies used to attain these goals.

The interactions of these communities have been considered as integral in the overall strategy adopted by ESTABLISH as shown in Figure 1 which can be contrasted with a more traditional view (Figure 1). ESTABLISH has provided the opportunity for these communities in second level science education to work together to achieve the specific aim of creating authentic learning environments for science education. This collaboration has informed the development of the project's teaching and learning materials (ESTABLISH Units) as well as educational supports for both in-service and pre-service teachers (ESTABLISH Teacher Education Programmes) designed to promote the use of Inquiry-Based Science Education (IBSE) in classrooms across Europe.

The term 'inquiry' has many different meanings and so in the ESTABLISH work, it was necessary to adopt a common understanding of inquiry. From extended group discussions, the individual elements of inquiry were identified and operationalized to represent the role of the student in an IBSE classroom, thus adopting the understanding of the inquiry process as the "*intentional process of diagnosing problems, critiquing experiments, and distinguishing alternatives, planning investigations, researching conjectures, searching for information, constructing models, debating with peers, and forming coherent arguments*" (Linn et al., 2004).



(a) (b)

Figure 1: Modes of interaction between science education communities (a) Traditional model; (b) ESTABLISH model.

To support the interactions shown in Figure 1, exemplar materials for IBSE were developed in the form of IBSE Units. The purpose of these IBSE Units was to provide examples of inquiry strategies and approaches that could be adapted for classrooms across Europe and that highlighted authentic learning examples. Additionally these resources were prepared for teachers to use but were also used in the teacher education programmes on inquiry. The framework for the development of these IBSE teaching and learning materials (IBSE units) was prepared and each Unit include sections that:

- highlight the role of inquiry and its relevance in the implementation of the Unit;
- provide the background scientific information, if deemed necessary;
- emphasise the Pedagogical Content Knowledge required;
- emphasise the Industrial Content Knowledge (see next section);
- include Student Learning Activities based on IBSE and aimed at encouraging and facilitating students to be the leading actor of his/her own learning;
- explicitly show different levels of IBSE, starting from the simplest ones, suited for complete beginners in IBSE, and possibly getting to the most demanding (for both students and teachers), open inquiry.

When under development, specific attention was focused to ensure that all materials are suited to both genders and also that adaptation was possible to take into account cultural differences and particular circumstances in different countries.

The ESTABLISH collaboration have developed a set of 18 IBSE Units, on topics shown in Table 1, each consisting of several smaller units directed at lower, middle or upper levels in second-level schools. In total these materials have 281 IBSE activities, many of which have been piloted in the classrooms of Europe. The aim of these units was to provide materials for a broad range of pedagogical situations (including teacher education), to be representative of

Inquiry Based Science Education (IBSE) appraoches and to show teachers the benefits of IBSE in classroom practice, inspiring them to generate their own IBSE materials.

Table 1: List of ESTABLISH Teaching and Learning Units (available at www.establish-fp7.eu)

Physics	Chemistry	Biology	Interdisciplinary Science
Sound	Exploring Holes	Disability	Forensic science
Heating & Cooling - Designing a low energy home	Chitosan – Fatmagnet?	Blood donation	Medical imaging
	Cosmetics	Ecology	Renewable energy
Direct current electricity	Chemical Care	Water in the Life of man	Photochemistry
Light	Plastics and Plastic Waste		Photosynthesis

INDUSTRIAL CONTENT KNOWLEDGE

As noted earlier, the teaching and learning units included an emphasis on industrial content knowledge (ICK). This term was coined to embrace the authentic learning experiences in the classroom i.e. on bridging the gap between the communities/knowledge of those who teach and learn about science and those whom use science as part of their daily lives. It should be noted that the term ‘industrial’ is not confined to heavy industrial processes per se but to any commercial or public organisation where science is applied and where people may be employed in scientific effort (e.g. market gardens, pharmacies, public services). ICK can be considered as knowledge of the relationship between the scientific topic under discussion (e.g. electrolysis) and the industrial application of such knowledge (e.g. electroplating). The application of a science is often referred to as ‘technology’. An important difference between science and technology is the goal: in technology the goal is the design of new products or processes, while in science the goal is to develop and understand new knowledge. It is clear an educator must address both of these aspects in their pedagogical approaches so as to develop in students problem solving approaches relevant for both science and technology.

ICK can relate to different levels of interaction between industry and the classroom. In ESTABLISH, it was useful to highlight five different levels of interaction from the lowest level, involving application or context, to a highest level where students solve industrial type problems. Table 2 summarises these main levels of interaction. Within the units developed, this classification is used to highlight the link between the IBSE activity and processes and products of industry and technology. This classification formed the basis of the design-principles for the development of all the materials/activities in this project.

From the descriptions given in Table 2, it is clear that ICK relates to more than just referring to an everyday context or application of science; it gives a framework to deepen engagement with everyday contexts and looks beyond the obvious applications. A particular example in the Unit on Disability, the use of glasses is highlighted with the ICK of visiting the local optician and glasses provider. In Chemical Care, the effects of washing powders are investigated in terms of outflows from washing machines, leading to the industrial problems of water treatment at the local water treatment plants.

Table 2: Industrial Content Knowledge – levels of interaction with industry

ICK Level	Description of level
I	The context of the activity has a link, but the activity is rather traditional. In such an activity for example the application of science content in a certain product or process is demonstrated.
II	In the activity initially an industry is studied, preferably by a site visit and challenges faced in that industry are used to introduce science activities. For instance 'safety in cars' lead to study the role of crushing zones, which will lead to related physics concepts.
III	Analysing an industries main product or process based on a site visit and study of both the science content and the design process/choices that have been made. Students should experience different solutions for the same design task.
IV	A design task informed by an industry. Students will need to follow all steps in a design process. During the process they will need to learn science concepts and do experiments.
V	A design task with a particular industry. In this case contacts with industry leads to a design problem.

ESTABLISH TEACHER EDUCATION PROGRAMMES

With the development of the ESTABLISH exemplar units, these formed the basis of teacher education programmes (TEP) developed within the context of the ESTABLISH project. The framework for ESTABLISH teacher education, as illustrated in **Error! Reference source not found.**, identified and described four core elements together with four supporting elements. This framework provided a flexible and comparable description for all ESTABLISH Teacher Education Programmes (TEPs) in the participating countries and required a minimum of 10 hours of face to face participation, with both in-service and pre-service teachers. The four Core Elements (I – IV) for teacher education were identified as:

I. ESTABLISH view of IBSE – outline of ESTABLISH view of inquiry, benefits to learning, role of inquiry in curriculum, provision of direct experience of inquiry.
II. Industrial Content Knowledge (ICK) – industrial linking – provision of authentic experiences informed by industry or real applications. In many cases study visits may be an appropriate way of meeting this objective.
III. Science Teacher as Implementer - followed by implementation in classroom – key area here is for the science teachers to be prepared for implementing inquiry teaching/learning in their own classroom, identifying and meeting any challenges.
IV. Science Teacher as Developer – evaluation of classroom experience; identification of further needs – teachers should have experience and be equipped to implement IBSE and start on the process of modifying their own materials to include inquiry.

Through these four core elements, teachers were able to discuss what inquiry was, different understandings of what inquiry processes were like in the classroom and also directly experience inquiry themselves as a learner. Through subsequent workshops, teachers experienced the potential of ICK and how it could change the learning experience of their students. The final two core elements encouraged the teachers to trial some aspect of inquiry in their classroom and then to discuss their experiences of that with the group; in this way, particular issues that may have arisen are discussed and proposals on how to deal with these issues were identified. Finally, the teachers were supported to adapt their own materials or develop new materials for their classes involving inquiry practices. Additionally, in order to support teachers to overcome reported barriers, a number of supporting workshops were developed by different partners to address the following Support Elements (V-VIII):

V. ICT – develop confidence and competence in the effective use of ICT.
VI. Argumentation – address skills to facilitate use argumentation in the classroom.
VII. Research and design projects – providing authentic experiences for student.
VIII. Assessment of IBSE – address assessment of inquiry learning.

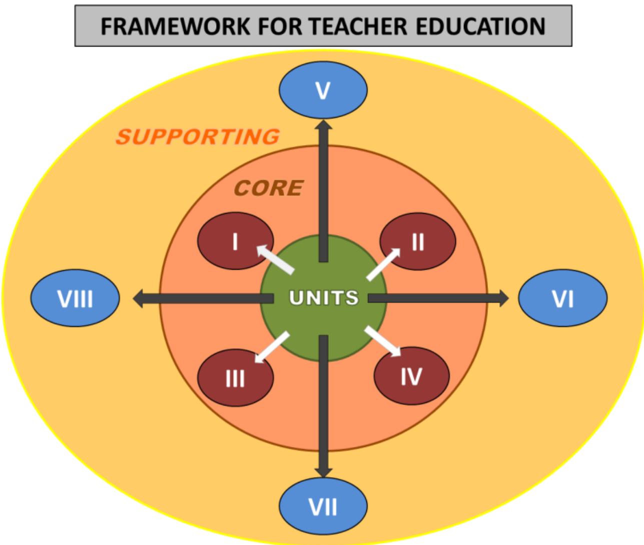


Figure 3: Framework for ESTABLISH in-service and pre-service teacher programmes.

Within the project, each country implemented elements I – IV in their in-service and pre-service science teacher education programmes but incorporated elements V-VIII as required by their group of teachers or as time allowed. Throughout the TEPs, the exemplar units were used to highlight good practice examples or to be a starting point for discussions. The range of materials developed through ESTABLISH and details of the TEP programmes are available at www.establish-fp7.eu.

CONCLUSIONS

The pan-European FP7-funded project ESTABLISH (2010-2014) collaboration has led to the development of teaching and learning materials as well as educational supports for both in-service and pre-service teachers designed to promote the use of Inquiry based approach at second level. The ESTABLISH consortium have provided teacher education programmes in IBSE to 2090 teachers across Europe, focused at the teaching and learning of science (Physics, Chemistry and Biology) at both lower and upper second level. A framework for the implementation of IBSE teacher education programmes has been developed and implemented by the consortium, across a range of cultural, educational and disciplinary contexts.

The objective of ESTABLISH to involve all stakeholders of science education, from practitioner to policy maker to design and develop, pilot and evaluate the implementation of inquiry in the classroom has been realised with positive impact on those involved. The entire collection of 18 ESTABLISH IBSE units, with a total of 281 activities, now provides an extensive bank of fit-for-purpose resources for teachers and educators in adopting IBSE and integrating Industrial Content Knowledge into classroom practice. All ESTABLISH materials are openly available at www.establish-fp7.eu.

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Assessment of Selected Biological Activity based on Inquiry at Lower Secondary

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This paper is focused on the verification of tools for formative assessment of IBSE activity within the project SAILS. The topic "Plant nutrition – photosynthesis of algae", was piloted at two schools in Košice, Slovakia. Pupils at the age of 12-13 and 15 years old observed colour changes of carbon dioxide indicator caused by carbon dioxide concentration change in the solution of immobilised algae as a result of effect of light intensity on the rate of photosynthesis. We assessed inquiry and reasoning skills. We have focused on key moments in which pupils could make the decision independently and proceeded in the experiment on the basis of their decision. We observed pupil's argumentation, work accuracy, methods of data recording, documentation the experiment and formulation of conclusion. Pupils were very skilled at documenting (own initiative) of experiment using available digital technology (cell phone). At the conclusions they rather expressed the experience of inquiry (colour change of indicator) than the fact that the change was caused by different rate of photosynthesis. It has been found out that younger pupils (12-13 aged) need the assistance when recording and interpreting data. They should have aids in the form of clear tables and graphs to help them realize that exactly the observed and recorded data of variables are important for formulation of conclusion.

INTRODUCTION

Whereas progress into science is based on experimenting it is important to develop practical skills. Opportunities for this are IBSE activities in the educational process of many science disciplines including biology. Students must be able to organise and regulate their own learning, to learn independently and in groups, and to overcome difficulties in the learning process (OECD, 2000). In terms of inquiry cycle biological practical exercises that are part of the thematic plans of all schools in Slovakia, may represent inquiry. Despite the possibilities of inquiry at practical exercises within biology lessons relatively few teachers focus on teaching through inquiry IBSE. Their approach or actually reluctance to innovate education this way justify by lack of tools for assessment, what is ultimately true. For developing of competencies based on acquisition of skills is more effective formative assessment. Therefore it is necessary to create a methodology and tools of assessment and identify key moments in which the student applies active inquiry. This study is aimed to determine the key moments suitable for assessment, and possibilities for formative assessment of inquiry based biology education – IBSE activity "Plant nutrition – photosynthesis of algae".

IMPORTANCE OF IBSE AT SCHOOL AND THE WAYS OF ITS ASSESSMENT

In modern societies, all of life is problem solving. Changes in society, the environment and in technology mean that the content of applicable knowledge evolves rapidly. It is generally agreed that inquiry science include some interactions with the everyday life as “problem solving” or “investigation”. Slovakia has long been under OECD average of PISA study in proficiency in problem solving and science skills. We should to create an opportunities to inspire the pupils interested in science, which understanding is the basis for development of science thus form development of their abilities for problem solving in general. Inquiry education in schools gives us the opportunity to achieve this aim.

Inquiry skills are some skills that are really important to scientists. Students can build these skills through science activities in school. In science classrooms, these include problem solving, planning and raising questions, collecting data, reasoning, researching and testing out their ideas. There are many answers to the question “What is scientific inquiry?” as a basic of inquiry based science education. This conception is inspired by scientific diagnosing problems and research procedures. Pre-done knowledge aren´t offered to pupils, they themselves create new knowledge based on the information which they acquired during their research activities and previous experience with that phenomenon in learning process or everyday life.

Inquiry-based learning requires many skills and strategies and a wide range of resources from beyond the school library and classroom (Alberta Learning, 2004). In the framework project 7RP ESTABLISH were designed and implemented an inquiry based activities which were piloted in many countries. In the present project SAILS is preparing teachers for assessment of IBSE activities at school. Learning through inquiry is a process of developing understanding which takes account of the way in which students learn best, that is, through their own physical and mental activity. It is based on recognition that ideas, knowledge and understanding are constructed by students through their own thinking about their experiences.

Also there are possible ways how to assess the inquiry at classroom. There is a difference to assessment of traditional education, in which was long term established summative assessment. Increasingly there is focus on formative approach to assessment. The inquiry model is based on more than 30 years of research from around the world, with thousands of children, adolescents and adults in a variety of inquiry settings (focus on inquiry PDF). There are different types and levels of inquiry-based teaching and learning. Each levels of inquiry published by Wenning (2005) can be in our view deduced from inquiry cycle (Fig. 1).

1) Interactive demonstration represents the active involvement of students in the last two of the six steps of the cycle, the previous teacher carries while leading a constructive dialogue with pupils. The teacher will demonstrate the phenomenon. Students in an interview with him contained context, formulate and present the conclusion and discuss about it.
2) In a guided discovery student's autonomy is extended to the fourth step proceed independently, but according to the instructions. Collect and process data.
3) In a guided inquiry students perform independently the third step: they themselves plan an investigation that will test the assumption.
4) Bounded inquiry is limited only by topic (problem). Students formulate a question of testing, respectively assumption or hypothesis.

5) Open (free) inquiry is the realization the whole inquiry cycle alone, the pupils themselves appear and identify the problem.

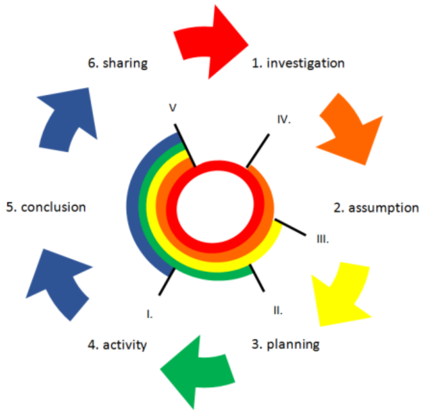

Figure 1: Active steps realized by the pupils (1st-6th) inquiry cycle IBSE at the level of inquiry 1-5.

Individual levels and steps of inquiry provide an opportunity for formative assessment of IBSE activity. Assessment used to support day-to-day instruction, called formative assessment, makes use of all the normal activities of a classroom. By Hein and Lee (2000), teacher can ask pupils several times during a unit to systematic recording of results, draw graphs, or provide a complete description of a scientific term. Such student products can inform teachers of what ideas have been understood by individual children and what needs to be done next. The method of solution of some activity or experiment is not immediately obvious. Assessing inquiry science requires that teacher documents student's science skills, such as the ability to observe, measure, and design experiments. For improving of these skills teachers effective feedback to student should to be provided in a timely manner (close to the act of learning production). Study of Nicol and Dick (2007) deals with good quality external feedback. They proposed that quality external feedback to students is information that helps students troubleshoot their own performance and self-correct: that is, it helps students take action to reduce the discrepancy between their intentions and the resulting effects. In an inquiry activity children should discuss, work in groups and teacher can judge how well students can solve problems, chose methods, which in IBSE aren´t immediately obvious, collect data and make assumptions.

It is clear that formative assessment is essential to the implementation of IBSE. On other hand assessment can be uniquely summative when the assessment stops at the judgement (Taras, 2009). Feedback from teachers is a source against which students can evaluate progress, and check out their own internal constructions of goals, criteria and standards (Nicol and Macfarlane-Dick, 2007).

ASSESSMENT OF SELECTED KEY MOMENTS OF IBSE ACTIVITY

IBSE activity "Plant nutrition – photosynthesis of algae", develops several inquiry steps. In this activity pupils use algae to watch the rate of photosynthesis. First part of the practical involves 'immobilising' the algae making jelly algal balls. Then pupils use them to determine the rate of carbon dioxide absorption, which indicates how fast photosynthesis proceeds. They can detect carbon dioxide absorption using hydrogen-carbonate indicator. The next step is very important to investigate the effect of light intensity on the rate of photosynthesis – pupils have to decide on the details of the quantities and how to vary the light intensity.

Considering the age and lack of experience work in the laboratory pupils did not plan the whole experiment alone. Students performed independently the third step of inquiry: they themselves planned an investigation and then tested the assumption. They applied guided inquiry. They made their own decisions just in three key-moments, and other actions were carried out according to instructions. Pupils worked in groups of three. They prepared a certain amount of algal balls in two steps. First algal cells were shuffled into the alginate solution. Then pupils made the balls by pouring the green mixture into a solution of calcium chloride. This first practical role that pupils enthusiastically mastered was followed by the first independent decision.

Assessment of Inquiry Plans

1) How to divide prepared balls equally into three experimental containers. First, pupils generated the ideas. They agreed that there are three possible ways: placed in each vessel the same number of balls, placed in each vessel the same amount of jelly balls weighed 3 times the same weight. Each group chose a way that seemed to be the best. They had noted the argument why they decided that way. For example one of the groups, thought that weighing is the fastest way. Others suggested that counting will be the most precise. Another group said that put three teaspoons of algal balls in each dish is the most practical. Others indicated that it will be more precisely to measure volume by measuring cup. They should continue prearranged manner in the experiment by chosen procedure.
2) Another opportunity for planning represented location (layout) of three samples supplemented by standard volume indicator at different distances from the light source. Specific distances in cm were not given in the instructions. Pupils groups should consult, and agree on an appropriate location.
3) Entry of constants and variables were also kept on their own choice. Pupil groups could agree what and how they would enrol after discussions about data which should be recorded (an indication of the amount of algae, volume of added indicator, the distance of samples from the lamp, the time change of the indicator) and the entry form (which can be put into a table and whether some data can be expressed as a graph).

We evaluated skills in planning how to distribute the material into equal parts during implementation (discussion groups) and immediately after the implementation of that step in a discussion with the whole class. The team that chose weighing concluded that it is not true that weighing is the fastest way of dividing. They needed to re-weigh, add and remove material. They agreed, however, that weighting is probably the most accurate of the proposed methods. Those, who dosed balls using a spoon, were quickly done, but they admitted, that this might not be the best way. There were visible differences between the amounts of material in the samples. It was better to measure the volume by a measuring cup. All agreed that counting jelly balls can be quite reliable method. This method was not chosen by any group, the procedure had seemed to be the most time consuming for them.

Layout of samples was evaluated in a discussion after a defined time. At the end of the experiment the pupils sorted on one line samples depending on how far from the lights have been placed. Pupils saw that those of them who thought that the greater distance between the first and the third sample is more apparent on the colour indicator, they were right. Planning layout of samples related to the way of thinking and foresight pupils. They must realize the role of light in photosynthesis. Thus, there must be a sufficient difference in light intensity, which treats on the individual samples.

Assessment of Data Presentation

Pupils could choose the form of enrolment themselves. Mostly pupils divided the tasks and just one of them was a writer, who was more an observer, while others realise the experiment. Their output was often based on the writer notes. Pupils themselves made out photo documentation, we didn't hinder them. They used the cell phones spontaneously. They can complete output at home in the form of digital presentation protocol or poster.

We expected that pupils, on the basis of discussion in the introduction, they should enter the weight of the material used in the sample, the amount of added indicator and the time of its action, when writing constants and variables. We supposed that pupils write a simple table into which enter three samples distance in cm from the light and colour of the indicator in each sample. We expected that the conclusion they indicate is that the colour of the indicator changed, because the sample closer to the light, is that where algae consumed more carbon dioxide from the solution.

We expected that pupils tried to organize the data entry in some table or graphs, but nobody chose this way of output presentation. Assessment of this step of inquiry should be realized by using of check list with simple table as a pattern, which they could more to recast.

Some pupils indicated in their output chosen procedure and also in what was its lack and recommendations on how to change it. Others indicated the procedure and lack thereof. Others indicated only the chosen procedure. Although at the beginning we talked with the pupils about the fact that for enrolment data could be used table, no one used this possibility. Their attention is focused on the activities, recording the results was secondary for them. Variables were incorporated in continuous text. It seems that younger pupils need to propose a table in a worksheet, aware of the importance and significance of data tables for clarity of enrolment.

EFFECTIVENESS OF FORMATIVE ASSESSMENT OF INQUIRY BASED ACTIVITY

Feedback, when used as part of a formative assessment system, is a powerful way to improve student achievement. Effective feedback as a result of formative assessment gives to each pupil guidance, how to improve in skills needed for achievement of inquiry goal. In its traditional form, formative assessment has been thought of as providing teachers with more frequent evidence of student's mastery of standards to help teachers make useful instructional decisions. In this way, formative assessment is intended to enhance student learning (Stiggins, 2005). The greatest value in formative assessment lies in teachers and students making use of results to improve real-time teaching and learning at every turn (Chappuis and Chappuis, 2008). Mastery of formative assessment by teacher is assumption for effective inquiry based education. At inquiry lesson formative assessment in IBSE means using questioning to help the development of student's ideas and competences, providing and using of effective feedback and inviting students to assess their work and generate possible steps for improving.

CONCLUSION

The third level of inquiry – guided inquiry was applied in this activity. Pupil didn't investigate a problem and make assumptions so we didn't assess these two first steps of inquiry. Moreover, identification of the problem seems to be difficult. We focused on assessment of the next steps of inquiry. We assessed pupil's skills when they participated in planning an experiment and their activity on course of the experiment. When pupils managed these steps we assessed their ability to collect data and make solid conclusion. In assessment of younger pupils for data collecting skills could be used some check list or another aid. If students managed all three steps (plan, activity, conclusion) we evaluated that they had all assumptions to share their results on good level with others. It was the assessment of the last step of inquiry cycle. We were able to assess only some of the key moments of IBSE activity because there are still not enough tools and methods for assessment, which could be like guidance for teacher during the inquiry education.

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A Study on the Engagement Levels of Mature and Traditional Students in Engineering with Mathematics Learning Support

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The Mathematics Learning Support Centre (MLSC) in the Dublin Institute of Technology (DIT) provides free mathematical support to all DIT students. This support is primarily delivered through a drop-in service, where students can receive one-to-one tuition, without an appointment, in any area of mathematics. In the first semester of the 2013/14 academic year a significant proportion (approximately 42%) of students that availed of this drop-in service were mature students enrolled in engineering programmes. This is of particular interest as mature students constitute a relatively small proportion of the total student body (approximately 15%), motivating a deeper study of the support offered to these students by the MLSC, their attitudes towards this service and the possible reasons behind the low engagement with traditional students. To this end focus groups were conducted in order to ascertain the attitudes of mature students in Engineering towards the MLSC and their views on the traditional student. In addition some quantitative analysis was carried to determine what effect the MLSC had on student's academic performance.

INTRODUCTION

In recent years an increasing number of students in Irish Higher Educational Institutions (HEIs) are taking courses with mathematical and statistical elements. This is in part due to the widespread recognition that mathematics underpins many other disciplines (such as Science, Technology and Engineering) and the emphasis placed by the Higher Educational Authority on producing graduates who are highly literate in mathematics (EGFSN 2008, HEA 2004).

Hand in hand with this increase however has come the so called 'Maths Problem'- that is a decline in the mathematical proficiency of incoming first year students across HEIs in Ireland and elsewhere (Gill 2008, Almeida *et al*. 2012, Carr *et al.* 2013 & 2013). This in turn is having a detrimental effect on enrolment and retention levels in science and technology courses in HEIs (OECD 1999). In fact, it is widely acknowledged that the absence of a solid foundation in mathematics can be one of the key inhibitors for student progression in higher education (HEA 2008).

As part of the response to this problem, Maths Learning Support Centres (MLSCs), defined by Lawson *et al* (2003) as '*a facility offered to students (not necessarily of mathematics) which is in addition to their regular programme of teaching through lectures, tutorials, seminars, problems classes, personal tutorials, etc.'* have been set up in the majority of HEIs in Ireland (Gill *et al.* 2010). In the UK over 85% of HEIS surveyed offer some form of Maths Learning Support (MLS) (Perkin *et al.* 2012), up from 62.3 % in 2004 and 48% in 2001 (Perkin *et al.* 2004, Lawson *et al.* 2001). It is therefore clear that MLS has now become an integral part of the higher educational framework, both in Ireland and the UK.

However despite this, MLSCs in several HEIs exist precariously, often lack permanent funding and are regularly in the ‘front line’ for spending cut backs (Macgillivray *et al.* 2011, Mac an Bhaird *et al.* 2013). To ensure that the limited funding available for MLS is put to the best possible use and to establish ‘Best Practice’, much time and resources have been put into researching methods of evaluating MLSCs’ activities. This evaluation can be undertaken using quantitative (usage figures, diagnostic testing, exam results etc.) and qualitative methods (focus groups, surveys, student feedback etc.) (Macgillivray *et al.* 2011). In a study on evaluation of the MLSC in Dublin City University, Ní Fhloinn found that a combination of both types of methods gave a more complete picture (Ní Fhloinn 2009). An extensive review of the literature on the evaluation of MLSCs can be found in (Matthews *et al.* 2012).

One important issue that arises from these evaluations is the non-engagement with MLS of so called ‘at risk’ students - those who are most in need of extra support. In a recent paper by Mac an Bhaird *et al.* (2013), details of a large scale study on student non-engagement with MLS across several Irish HEIs are given. The study found that the main reason students gave for non-engagement was that they did not need help. However this was more likely to have come from a student with a strong mathematical background. For the weaker ‘at risk’ students, issues with the structures of the MLS such as unsuitable opening hours or a lack of information were more likely to be cited as a reason for non-attendance. Symonds (2008) questions whether these reasons are valid and wonders if implementing the requested changes in structures would actually serve to increase the engagement levels of these students. This suggests that a deeper study into the reasons of student non-engagement with MLS, in particular for those ‘at risk’ students, is required to get to the root of the non-engagement problem.

In this paper, the authors seek to further this investigation by looking at the engagement levels of mature students with the MLSC in the Dublin Institute of Technology (DIT). In the DIT a mature student is defined as being ‘*any Irish or EU citizen who will be 23 years of age on the 1st of January of the proposed year of entry’* (DIT Website). The authors examine qualitatively the reasons behind both the engagement and non-engagement of this cohort of students with the MLSC and their views on the low engagement levels of the traditional student. In addition, a brief quantitative study is performed on the effect of the MLSC on these students’ academic performance.

METHODS

This study seeks to examine the reasons behind both the engagement and non-engagement of students with the MLSC in the DIT, as well as investigating how the MLSC has influenced the academic performance of mature students who have regularly availed of its services. The authors decided to use a mixed method approach by combining both quantitative and qualitative methods of research. Qualitative researchers are interested in understanding the meaning people have constructed from their lived experiences (Merriam, 2009). Hence, qualitative methods of enquiry and analysis are more suitable when humans are the instruments of enquiry. This is why the authors decided on a study of this nature. However, in order to evaluate the academic progress of mature students who have been attending the MLSC a quantitative measure is needed. Much research supports this integration of quantitative and qualitative research. The use of multiple methods reflects an attempt to secure an in-depth understanding of the research and allows for broader and better results (Denzin and Lincoln, 2005).

Participants

The participants for this study comprised of mature students in their first year of an Engineering undergraduate programme in the DIT. As mentioned previously, in the DIT a mature student is defined as being '*any Irish or EU citizen who will be 23 years of age on the 1st of January of the proposed year of entry'*.

Qualitative Data

In order to get feedback regarding why students attend/do not attend the MLSC, two focus groups were conducted. The first group (Focus Group 1) was made up of mature students whose attendance in the MLSC was constant throughout the year. The second group (Focus Group 2) was made up of mature students who had never attended the MLSC. Each student was coded to ensure confidentially. There were ten students in Focus Group 1 (P1 – P10) and four students in Focus Group 2 (P11 – P14). Their responses were transcribed and analysed using NVivo software and arranged into themes by the authors.

Quantitative Data

In order to get a quantitative measure of how the MLSC influenced the academic performance of mature students who regularly availed of its services, the authors decided to compare the grades of mature students who attended the MLSC with those who didn't. The objective was to investigate if the MLSC had any effect on their grades. The authors understand that there may have been other variables which may have affected the students' grades throughout the year.

RESULTS AND FINDINGS

Focus Group Findings

In this section the main themes that arose during the focus groups are outlined. There will be particular focus on the three topics most relevant to this paper namely what motives mature students to attend the MLS, the reasons given by these students for non-attendance and their attitudes towards traditional students.

Motivation

During the course of the focus group, it became clear that the motivations of mature students who attend the MLSC were multi-faceted.

The initial motivations that were raised were of a practical nature, such as financial motivation (not being able to afford private tuition) or simply a lack of availability of any other form of support

P1: *I didn't even do a Junior Cert and I'm doing mechanical engineering maths and I've had straight A's through and that's through the Learning Centre you know. I can't afford grinds you know.*

P2: *There's no other, no other help available. That's what I found. If you're looking for extra help as well, every door would be closed.*

An interesting theme that arose was the concept that it was the nature of mathematics itself, and its difference from other subjects, which motivated students to seek extra help. They experienced difficulties with self-study and keeping up with the pace of lectures.

P1: *Whereas maths, you have something at the start of a page and something at the end and if you don't understand the bit in the middle, unless somebody points their finger at it and says to you "this is what's happening". If you don't get it you don't get it.*

P1: *I find with maths in particular of all the subjects........Unless you get a hold of the stuff in September and you're doing October's work you haven't a hope, if you don't understand the basics of stuff you haven't a hope. So I found going to the learning centre each week, staying on top, learning whatever was current, you'd go in and you'd actually learn from the lecture as well.*

Related to this theme, some students stated that while they found self-study aids (such as textbooks or online mathematical resources) useful, it was their belief that these aids are not a replacement for one-to-one support, such as that offered in the MLSC.

P2: *They're all fairly good but you still need the one-on-one. Because you can keep pausing and rewinding and going backwards and forwards but you need the one-on-one....When you've got no basic level there's only so much a video or a book can teach you*

A widely held view among the participants was that the mature students' life experiences serve to motivate them to seek out the extra support offered by the MLSC.

P7: *because I'm guessing most of us have experienced what it's like to struggle through jobs and that kind of stuff and realise the importance of getting a decent qualification behind you and doing something you actually like.....*

P7: *it's that experience of having been at the bottom, you know and having to try and survive at the bottom, that you realise that when you get an opportunity like this, just how important it is to really avail of all the services, in my opinion the Maths Learning Centre being the most important that I've come across so far as an extra aid on top of your coursework and stuff like that.*

Finally, the participants noted that they are not just interested in passing the exams, but that they wish to gain a deeper understanding of the subject. They recognise, again possibly based upon their life experiences, the importance of possessing more than just a surface level knowledge of their chosen subject area.

P9: *but I want to be able to understand it you know, I want to be able to like if I go to a job interview and somebody puts a problem in front of me I want to be able to know what it's about…….I want to comprehend it basically and if I need that extra bit of support, which you do get in the Maths Support Centre then I'll take advantage of it.*

Reasons For Non-Engagement

This section outlines the main reasons given for the non-engagement of mature students with the MLSC. In a recent large scale survey on the issue of student non-engagement with MLS in Irish HEIs, it was found the main reason given by students who did not avail of service was that they did not believe they needed it (Mac an Bhaird *et al*. 2013). This finding was supported in our study.

P13*: I haven't really had a problem that I couldn't track down an answer to myself with google, YouTube or any of that.*

Mac an Bhaird *et al* (2013) found that the second most common reason given for non-attendance were issues with the structural organisation of MLS in their HEI e.g. opening hours, room size etc. This theme also arose during our study.

P13*: if it was at a different time during the day that would suit me.*

P7: *I found that the only thing that kind of stopped me from going was the size of the room and at certain times because of how packed it is*

In Irish HEIs, several programmes are run to ease the transition of mature students back to education. During the focus groups, it was noted that mature students who have attended one of these transition programmes, appear to have less of a need for the services of the MLSC then those who have entered directly into their undergraduate programme.

P13: *Some mature students have a problem I think. Since they finished the LC and come back into college it has been 5-10 years. Not studied anything... I did last year mechanical engineering, this year I am ok.*

P11: *I wasn't too bad because I did Fetac 5 last year and it had engineering maths in it as well.*

Perception of Traditional Students

As stated in the abstract, the engagement levels of the mature student are much greater than that of the traditional student. In this final section we will outline the views of our participants on both this discrepancy and traditional students in general.

There appears to be a perception among mature students that traditional students, having come straight from second level, are better prepared for the material in the programmes, in particular the mathematical aspects. Hence, they may not need the services of the MLSC as much as the mature student.

P6: *all the students that came straight from the leaving cert they'll just all get it, they'll understand it in all those two hours where I'll just sorta pick it up at the end cause I haven't done it in years*

P7: *and we're starting right from the bottom and we have not done it in years*

The participants also raised the point that the non-compulsory nature of MLS may have a negative effect on engagement with the traditional student

P1: *I think an awful lot of them as well maybe would have intentions of going to the learning centre but it would eat into their social time. I mean an awful lot of them don't go to lectures*

P5: *they don't have to go so they don't bother.*

They noted that perhaps the inexperience and lack of confidence of youth could have a negative effect on engagement. The traditional student may tend to be more reticent about asking for help than the mature student would be.

P9: *I know for a fact that a lot of them are struggling but they just don't realise the opportunity that is there you know and they are too young to take advantage of it.*

P10: *I just think they are intimidated to ask for help whereas mature people like ourselves we want to pass so we know we have to do it… We're not afraid to go here look I need help and ask for it and stuff*

The final viewpoint that was raised was on peer support. The participants noted that, in their experience, the traditional student would rely more on peer support than the mature student. They are more likely to work together in large groups and hence are less in need of MLS than a mature student may be.

P1: *but they pick an awful lot of stuff up off each other as well whereas if they're struggling with something if you are sitting around with ten or fifteen of the lads you know what I mean, they would talk about things a bit more they would but mature students would tend to stay in* *smaller groups you know what I mean and you would share stuff, you would learn stuff off each other but not as quick as the younger lads.*

Quantitative Findings

The study focused on one particular group of students, who were undertaking their first year of an ordinary degree in mechanical engineering and compared the end of semester exam results of those in this group who did and did not attend the MLSC in that semester. There were 20 mature students in this cohort. Of these students 8 had attended the MLSC and 12 had never attended. Of the 8 students who attended, 2 dropped out of the course after the first few weeks so there was no data on their performance. For the 18 students who remained, their performance in the semester 1 mathematics module was compared (See Table 1).

The average mark of those who attended the MLSC was higher but not significantly so (t-test, p= 0.25). It is not possible to determine if the two groups were the same or different to begin with as many of these students are international students, and many of the Irish students had not finished secondary school. Hence there is no single metric to compare their mathematical ability on entry. There is a DIT mathematics diagnostic test given to many students on entry but it was not given to this cohort.

Table 2: A comparison of end of semester exam results of those who did/did not attend the MLSC

Attended MLSC	N	Mean	Standard deviation
Yes	6	80.6	18.9
No	12	68.4	23

In addition, the proportion of both groups of students that achieved a grade of more than 60% was examined (See Table 2). All the students who attended the MLSC achieved a mark of greater than 60%. However, using Fishers exact test, it was found that the difference in these proportions was again not statistically significant (p=0.52).

Table 3: A comparison of the proportion of students who did/did not attend the MLSC that achieved a mark higher/lower than 60%.

Attended Centre	N	>60	< 60
Yes	6	6	0
No	12	9	3

It is a limitation of this study that this analysis was only for a small number of students in one course. The two students who attended but dropped out early are excluded and there is no metric for ranking the students on entry.

CONCLUSIONS AND FUTURE WORK

In this paper the authors investigated the reasons behind both the attendance and non-engagement of mature students with the MLSC in the DIT. Two focus groups were conducted with some interesting qualitative findings. The motivations of mature students were found to be multi-faceted, ranging from practical reasons, such as financial motivation, to more complex reasons such as their life experiences as adults motivating them to seek out extra help. The notion that mature students are interested not just in passing their exams, but also in gaining a deeper understanding of their chosen subjects was raised. The importance of one-to-one support in a student's development as an independent learner, even with the widespread availability of online resources, was also stressed.

For those students who did not avail of the services offered by the MLSC, the reasons given were mostly in line with the literature (Mac an Bhaird *et al* 2013), for example a lack of need for the service or issues with the structures of the MLSC. An interesting point raised was that mature students who have had a transition year prior to beginning their programme may have less need for extra support than those who have not attended such a course.

The participants were also asked to give their thoughts on the low engagement levels of traditional students. They noted that traditional students, having come straight from second level, are generally better prepared for third level mathematics. The non- compulsory nature of MLS as well as the reticence of younger students to seek extra support, were also cited as possible reasons for non-engagement. The final issue raised was the notion that traditional students tend to rely more on peer support, e.g. studying in groups, than the mature student would and hence would have less need for the extra support offered by the MLSC.

On the quantitative side, the authors examined the end of semester exam results of one group of students. They found that while the mean grade of those who attended the MLSC was higher than those who did not, the difference was not statistically significant ($p=0.25$). In addition the difference between the proportion of both groups that achieved over 60% in the end of semester exam was not statistically significant ($p=0.52$). These results must be viewed with a certain amount of caution however, as there was no common baseline for comparison of students' exams scores (e.g. diagnostic test results) and the sample size was small and is not random.

Future Work

The authors intend to conduct focus groups involving traditional students to investigate the non-engagement further. The authors also wish to extend the quantitative analysis of this study to a much larger group of students, including tradational students, and to benchmark students on entry using the DIT mathematics diagnostics test, in line with Carr *et al.* (2013).

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TEMI: Teaching Enquiry with Mysteries Incorporated

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TEMI is an acronym for Teaching Enquiry with Mysteries Incorporated (http://teachingmysteries.eu/en). TEMI is a new FP7 Science and Society project, which started in mid 2013 and will run for three and a half years. The project is part of a response from the European Commission to tackle "the alarming decline in young peoples' interest for key science studies and mathematics" (Rocard et al 2007), with a focus on Inquiry-Based Science Education (IBSE). TEMI aims to work with schools across Europe to develop and implement innovative training programmes, which assist teachers in using enquiry to teach science. Science teachers across Europe will develop teaching methods using mysteries, unexplained or discrepant events to improve their ability to capture the attention of their students. The idea is to use the mysteries or discrepant events to arouse and engage student interest at the beginning of a lesson, which will then motivate students to enquire further and find out the scientific explanations. The mysteries or unexplained events engage the observer in the learning process, which is the first step of the 5E enquiry process. Each partner of the project will work with 5 or 6 cohorts of science teachers in a series of two one-day workshops. In between the workshops teachers will trial and evaluate the TEMI ideas in their schools and will develop TEMI lessons themselves based on these ideas.

The TEMI project is coordinated by Queen Mary College, University of London. The other partners include: Sheffield Hallam University (UK), University of Bremen (Germany), The Weizmann Institute (Israel), University of Limerick (Ireland), University of Vienna (Austria), University of Milan (Italy), Leiden University (Netherlands), Charles University, Prague (Czech Republic), Sterren Laboratory (Netherlands), Hogskolen in Vestfold (Norway), CNOTINFOR (Portugal), TRACES (France). The University of Limerick (UL) are the Irish partners in the TEMI project. The UL TEMI team have been working with 4 pre-service science teachers over the past year in developing materials for the TEMI lessons. These materials have been used in the first Teacher Training Workshop which took place in January 2014. The participants of the first workshop experienced IBSE in the form of a TEMI lesson, they were informed about the 5E model as a framework for IBSE, helped in developing their own TEMI lessons and were provided with an initial bank of prepared TEMI lesson ideas. Details of the first and second (April 2014)

TEMI Teacher Training Workshops and the participation of the pre-service and in-service teachers of Cohort 1 in Ireland will be outlined in the paper, together with examples of the TEMI materials and approach.

ENGAGING THE DISENGAGED: THE TEMI APPROACH

Introduction

Harnessing the emotional power of magic, myth and mystery is one of the latest trends in science education. TEMI, the EU-funded FP7 Science in Society project is attempting to promote enquiry-based teaching to help young students across Europe develop a passion for science. The aim of this three and a half year teacher training project is to help transform science and mathematics teaching practice across Europe by giving teachers new skills to engage with their students, exciting new resources and the extended support needed to introduce enquiry-based learning into their classrooms effectively. Innovative workshops are being developed among teacher training institutions and teacher networks across Europe which will be based around the core scientific concepts and emotionally engaging activity of solving mysteries, i.e. exploring the unknown. It is intended to train 5-6 cohorts of 10-12 teachers over the course of the three and a half year project, in each country, in a series of workshops. A spoke-and-hub model for coordination and delivery allows the project to both respond to local country needs and to maintain an overall EU-wide sharing of best practices. The central hub of this project is the coordinator Queen Mary University of London, while the spokes comprise of 13 partners from 11 countries (see Table 1).

Table 1: Consortium of the TEMI Project

TEMI Partners	
Queen Mary, University of London	UK
Università degli Studi di Milano	Italy
Bremen University	Germany
University of Limerick	Ireland
Sheffield Hallam University	UK
Hogskolen I Vestfold	Norway
University of Vienna	Austria
Weizmann Institute	Israel
Leiden University	Netherlands
Charles University Prague	Czech Republic
Sterrenlab	Netherlands
TRACES	France
Cnotinfor	Portugal

The 5E Model of Enquiry

The TEMI project is based on the 5E Model of Enquiry (Bybee et al. 2006), as shown in Figure 1.

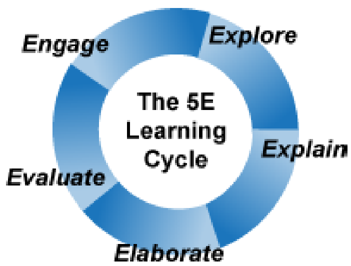


Figure 1: The 5E Model of Enquiry

In this model the lesson proceeds through a number of stages (Table 2), of which the first one is engagement. The particular focus of the TEMI project is on this stage of the lesson. Unless students are engaged and motivated, and have their curiosity aroused so that they start asking questions: “Why? How? What if?”, then there will be no real enquiry. The idea behind TEMI is to use mysteries, unusual or discrepant events, to capture the students’ interest and lead them into the 5E process.

Table 2: The Stages of the 5E Model (Bybee et al. 2006)

Engagement	Students’ prior knowledge accessed and interest engaged in the phenomenon
Exploration	Students participate in an activity that facilitates conceptual change
Explanation	Students generate an explanation of the phenomenon
Elaboration	Students' understanding of the phenomenon challenged and deepened through new experiences
Evaluation	Students assess their understanding of the phenomenon

What is a Mystery?

In science education, a mystery is a phenomenon or event that provokes the perception of suspense and wonder in the learner, in order to initiate an emotionally-laden “want to know”-feeling, which leads to an increase in curiosity and which initiates the posing of questions by the students, to be answered by enquiry and problem-solving activities (TEMI 2013). Such mysteries, which have a scientific basis and explanation, are also known in the literature as discrepant events. There is a large body of literature describing discrepant events and their role in science education to facilitate learner understanding and motivation (Liem 1990; O’Brien 2010).

A mystery is a good mystery for classroom enquiry if:

- it can be investigated and explained scientifically and is within the competency of the students involved,
- it provides affective engagement for the students,
- it generates curiosity and leads to student questions,
- it ‘problemmatises’ or makes knowledge and enquiry skills part of the answer to the mystery,
- it covers a sufficient part of the nationally assessed curriculum to justify time spent,
- it is simple enough to be a ‘discrepant event’, and generate cognitive conflict,
- the time between mystery and answer is limited (1-2 lessons),
- it is introduced by a pedagogy that relies on the mystery itself.

A mystery is a bad mystery for classroom enquiry if:

- it provides engagement for the teacher only, but the students are not excited,
- it generates little curiosity and the teacher has to do all the work,
- it is answered by science concepts that are too difficult for students to grasp,
- it is peripheral or unrelated to the subject content of the curriculum,
- it is too complex, so that students explain it away as 'magic' (a trick that I don't need to explain).

(TEMI 2013)

The various partners involved in this project are tasked with developing lessons around such scientific mysteries, introducing them to practising science teachers, who will try them out in schools and evaluate their effectiveness in engaging their students.

TEMI TEACHER TRAINING IN IRELAND

The Teacher Training Workshops for the 5 cohorts of teachers to be involved over the course of the project in Ireland have been mapped out below in Figure 2. It is predicted that over 60 in-service and 12 pre-service science teachers will participate in the project in Ireland. Each cohort of teachers will be numbered as 1,2,3,4 and 5. As each cohort will attend two full-day training workshops, the workshops have been labeled as 1.1 and 1.2 for Cohort 1, and will be labeled as 2.1 and 2.2 for Cohort 2 etc. To facilitate the sustainability of the TEMI Teacher Training in each participating school, two teachers from each school will attend TEMI Teacher Training Workshops in successive cohorts. In that way, one teacher from school A will attend the workshops as part of Cohort 1 and a second teacher from school A will attend as part of Cohort 2. The aim of this cascading model is to provide support for individual teachers within their school as they develop and trial TEMI teaching ideas, hence increasing the influence that the TEMI project can have on science teaching in the participating schools.

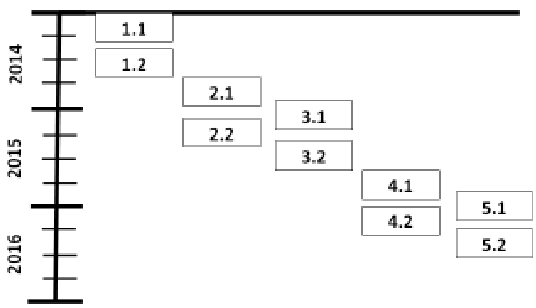


Figure 2: Map of TEMI Teacher Training Jan 2014 to June 2016.

Pilot Teacher Training

As outlined in Figure 2, the first cohort of teachers completed their TEMI Teacher Training in April 2014. Their first workshop (1.1) was in January 2014 and their second workshop (1.2) was in April 2014. This first cohort was composed of 4 pre-service science teachers and 5 in-service science teachers.

Role of the Pre-Service Science Teachers

The pre-service science teachers were in their final year of a four-year Science Education teaching degree programme in the University of Limerick. As part of their Final Year Research Project (FYRP), the students developed classroom teaching materials in the form of TEMI lesson plans and activity sheets in the areas of chemistry, physics and biology (for both the Junior Cycle – general science, and the Senior Cycle – single subject science). One of the students developed an 8 week science module for Transition Year science students, Scientific Mysteries, which includes physics, chemistry and biology units. The pre-service science teachers trialled and evaluated the developed TEMI classroom materials while completing their final year school placement (Sept- Dec 2013). The Transition Year module was also piloted by a number of the in-service science teachers in advance of workshop 1.1 in January 2014. The pre-service science teachers played a key role in the TEMI Teacher Training by:

- Providing information to the in-service teachers on how they sourced and developed TEMI classroom ideas.
- Providing feedback on their own experiences of implementing the TEMI lessons.
- Providing feedback on their pupils' learning experiences and attitudes towards the TEMI lessons.
- Mentoring and facilitating in-service teachers in developing and planning new TEMI ideas.

Workshop1.1

This was the first TEMI Teacher Training Workshop. The workshop was divided into 4 sessions which are detailed in Table 3. At this workshop, participating teachers were provided with a resource folder containing all of the necessary documents for their participation in the TEMI project. The contents of this folder included a list of all TEMI contacts and participants in Ireland, previously developed TEMI ideas, Lesson Planner templates to guide the development of their own lessons, as well as selected relevant literature about IBSE and the 5E Model.

Table 3: Content of TEMI Teacher Training Workshop 1.1.

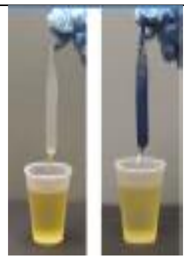
Session	Outline
1	Vision for TEMI project in Ireland TEMI enquiry lesson simulation 5-E model
2	Teaching to Motivate
3	Teaching Mysteries Designing a TEMI lesson
4	TEMI lesson resources TEMI Community of Practice

The in-service teachers found the workshop very useful as it was "applicable to real life & work of the teacher". They enjoyed working on a possible TEMI lesson in the workshop, with a suggestion of allowing more time for such lesson planning. The use of the Google + and Google Drive platforms was praised by the teachers as they found them to be "really helpful resources for future reference". Some teachers had previously "tried to implement mystery/enquiry into [their] lessons" but thought that it was "nice to have a structure" to do this. One teacher explained how they found it "extremely useful to be reminded to reflect on what [they] are doing in classrooms as teachers & how to develop & improve student experience[s]". The teachers were conscious that a lot of time and effort is required for this project but they believe that "the benefits and positive aspects are huge". One concern that was raised by the teachers was that using a discrepant event to introduce a scientific concept may be too challenging for lower ability pupils. The teachers felt that this teaching approach would be more suited for higher ability pupils.

TEMI Lesson Ideas

In the intervening time between both workshops, the in-service teachers trialed 5 of the TEMI lesson ideas that were developed by the pre-service teachers. They also developed 2 TEMI lessons of their own where they chose their own topics within the Junior and Senior Cycle science curricula. The lesson ideas were prepared using a structured Lesson Planner and the details were then organized on a prepared Lesson Template. Each of the teachers completed the TEMI Lesson Templates for each developed lesson. This document then provided all of the details for another teacher to use the TEMI idea e.g. the scientific concepts, appropriate age levels, necessary prior knowledge, preparation of chemicals and materials, safety hazards, resources for pupil exploration, extension activities etc. Table 4 provides some examples of the TEMI lesson ideas developed by the science teachers in cohort 1.

Table 4: TEMI Lesson Ideas Developed by the Teachers in Cohort 1.

Subject (topic)	Lesson Name	Brief Description	
Biology (The Digestive System)	A Lot of Guts!	The sizes of the 'small' and 'large' intestines are compared by presenting lengths of rope representing both. The importance of their size in relation to their function is investigated.	
Biology (Osmosis, Diffusion)	The Leaking Bag!	Osmosis and diffusion are explored by immersing a fully sealed zip-lock bag (or dialysis tubing) containing a starch solution into a beaker of iodine solution.	

Chemistry (Redox)	Decolourising $KMnO_4$ with steel wool	To introduce the topic of oxidation and reduction by introducing potassium permanganate as a strong oxidising agent.	
Chemistry (Water, Bonding, Solutions)	Burly Bubbles	Compare the properties of homemade (water and washing up liquid) bubble solution with burly (water, washing up liquid and glycerol) bubble solution.	
Physics (Pressure)	Under Pressure	To introduce the topic of pressure, a balloon is pressed against a bed of nails. However, the balloon does not burst easily.	
Physics (Boyle's Law, Atmospheric Pressure)	Boyle-ing Point	Differential pressures cause water to be 'sucked up' into an upside-down wine bottle.	

Workshop 1.2

The second TEMI Teacher Training Workshop for Cohort 1 was held in April 2014. Table 5 provides a brief outline of the content of the full-day workshop.

Table 5: Content of TEMI Teacher Training Workshop 1.2.

Session	Outline
1	Feedback from in-service teachers Feedback from pre-service teachers
2	Engage Phase: In the chemistry laboratory
3	Implementing enquiry throughout a lesson Developing a complete TEMI lesson Alternative types of mysteries
4	Sustainability of TEMI

The second workshop was mostly led by the in-service and pre-service science teachers, as each of them gave presentations on their work. This is following the Gradual Release of Responsibility Model (Fisher 2008), following the dictum: 'I do it, we do it, they do it.' The overall aim of UL's TEMI Workshops is to transfer ownership of the TEMI idea to the participating in-service and pre-service science teachers, so that they in turn will be able to pass this on to their students. According to the teachers in the second workshop, they enjoyed sharing their experiences of developing and trialling the TEMI lessons. Much of the feedback from the teachers was similar. Interesting points that the teachers agreed on included:

- The TEMI lessons were better received by Junior and Senior Cycle classes rather than pupils in Transition Year.
- The lower-ability pupils engaged and participated better in the TEMI lessons than the pupils who are usually 'high-achievers' in the classroom.
- That it was very easy to source TEMI lesson ideas and resources online.

The laboratory session was the teachers' favourite part of this workshop. In this session, each of the in-service teachers had the opportunity to teach the 'Engage 'part of their TEMI lesson in the chemistry laboratory. This gave the teachers an opportunity to share the ideas that they had developed and also to gain further feedback from the whole cohort on adaptations that could be made to their ideas.

PARTICIPATING TEACHERS' EXPERIENCES

All of the participants (pre-service and in-service teachers) completed an evaluation form at the end of both TEMI Teacher Training Workshops. Teachers' confidence ratings in sourcing, developing and implementing TEMI lesson ideas after both workshops were quite high, with confidence ratings of over 4.4 on the 5 point Likert-Rating Scale. At the end of Workshop 1.2, the teachers noted how they would still have liked further time to learn how to implement the other four E's of the 5E Model following engagement; exploration, explanation, elaboration and evaluation. All of the teachers were intent on using the TEMI ideas in their future teaching. 37% of the teachers said that they would implement the TEMI ideas as they have been presented in the TEMI project, while the majority of the teachers (63%) said that they would adapt the TEMI lesson ideas to implement them with other teaching approaches. It is intention of all TEMI partners to revise subsequent workshops in the light of our experience following a partners' meeting in November 2014.

Final Teacher Questionnaires

Overall, the in-service science teachers enjoyed their experience in the TEMI project. They felt that it "improved [their] teaching", and has provided them with "new ideas, resources and motivation". Some teachers commented on how they liked the opportunity to have to use their "creativity and personal ideas" for the development of their own lessons and all teachers noted that they would continue to use TEMI teaching ideas in their future teaching. Interestingly, it was reiterated by one of the teachers that the "challenging and fun" ideas in the TEMI lessons benefitted the academically "weaker" pupils as the academically "stronger" pupils "were less engaged by the mysteries".

It was agreed by all of the teachers that the 5E Model of Enquiry is a good approach to use in science teaching. Of the 14 trialled 5E TEMI lessons, 11 of those lessons motivated pupils to understand the underlying scientific concepts, with teachers being unsure about 3 of those lessons in their ability to motivate pupils to enquire further. The development of pupils' conceptual understanding was not affected negatively by using the TEMI approach, according to the participating in-service teachers. Furthermore, 11 of the 14 trialled TEMI lessons were reported as being easier to use to teach the particular topics as opposed to teachers using their usual lesson plans. No teacher was of the opinion that the TEMI lessons were more difficult to use to teach a topic than their usual teaching approach. It was pointed out by one teacher however, that the TEMI approach is "less suitable at Leaving Certificate level, or at least may need to be modified, as large amounts of information needs to be 'covered' in each lesson".

WHAT IS UNIQUE ABOUT TEMI?

TEMI is an EU funded IBSE project. However, the approaches taken in the implementation of the Teacher Training and development of resources in this project are unique from other such projects.

Cascading Recruitment of Teachers

As outlined in the introduction and illustrated in Figure 2, a cascading mechanism has been adopted in the recruitment strategy for teachers in the TEMI project. In this manner, participating teachers will not be isolated in their attempts to trial new ideas and reform their teaching approaches. By having more than one teacher implementing the 5E Model of Enquiry in a school, pupils may also develop better enquiry skills and become more familiar with the teaching approach. Hence, each cohort of TEMI teachers will be encouraged to involve other science teachers in their schools by sharing their experiences and materials, acting as mentors in their own schools. Figure 4 summarizes some of the ways in which the first cohort of in-service teachers intend to recruit their colleagues for participation in future cohorts.

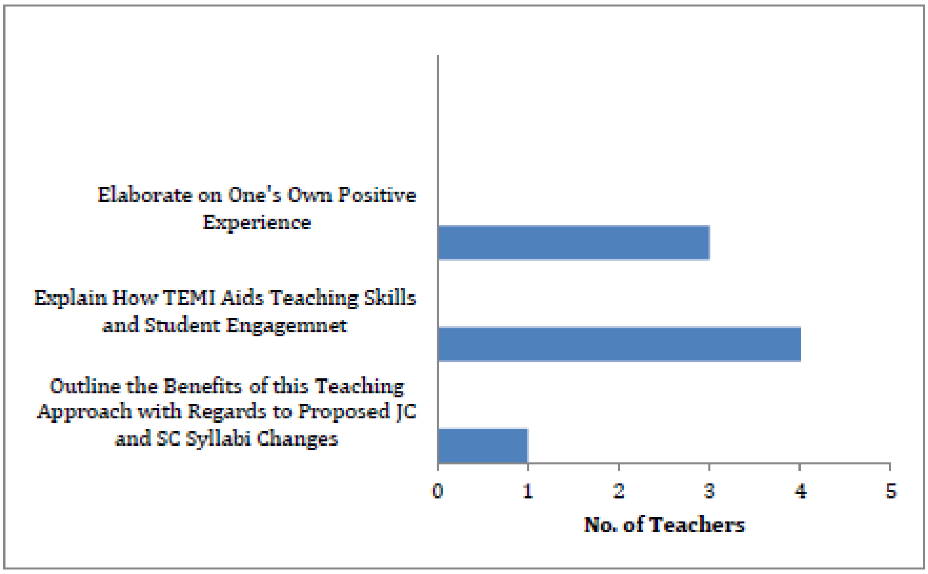


Figure 4: How Teachers Plan to Recruit their Colleagues to Participate in TEMI

Teacher Participation

Although the authors of this paper are the core Irish TEMI team, they see themselves as facilitators of pre-service and in-service science teachers' professional development. In the TEMI Teacher Training Workshops, teachers are given the opportunity to lead and direct their own learning. The pre-service teachers in Cohort 1 led the development of TEMI lessons. The in-service teachers had input into the planning for workshop 1.2. The areas of expertise of the individual in-service teachers were used by the UL team to enhance the teacher participation in both workshops. One of the sessions in Workshop 1.1 and three of the sessions in Workshop 1.2 were teacher-led. One teacher from cohort 1 will be involved as 'lead' teacher in cohort 2. This model of teacher participation will be continued in the following cohorts. By giving the teachers more ownership over their personal development in this project, the teachers were confident and honest in discussing the challenges they faced in a supportive environment.

Pre-Service Science Teacher Participation

The Irish TEMI team believes that involving pre-service science teachers in the project from the beginning has been a valuable part of the project, both for the participating students and for the teachers. They have made significant contributions in developing lesson materials and in doing preliminary evaluations of them as part of their FYRPs. We hope to continue this in subsequent years and also to provide training workshops on the TEMI approach and materials for a wider group ofpre-service science teachers in UL.

Virtual Community of Practice

A TEMI (Ireland) Community of Practice has been established with the first cohort of participants. To facilitate communication between all participants between the workshops and following the final workshop, a virtual community was set up using the Google™ Community. The aim of the TEMI (Ireland) Google forum is to allow teachers and the UL TEMI team to easily interact with each other online and to share their experiences of implementing TEMI lessons. The TEMI Google Drive folder, which is an online cloud storage facility, serves as a storage bank for the developed curriculum materials. This will be continuously added to by the team members and participants of future cohorts throughout this project. It is intended that all members involved in all cohorts of the TEMI project will continue to use and develop TEMI-style materials after their own workshops. All teachers in the community of practice will be able to use the resources throughout the lifetime of the project and after the project has ended. The idea is to develop a continuing community of practice with pre-service and in-service teachers and science education researchers for the duration of the project and beyond.

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The Particulate Nature of Matter, Inquiry Based Learning and the Transformative Education of Junior Secondary School Students

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This work is directed towards promoting students understanding of the Particulate Nature of Matter (PNM) through Inquiry Based Learning (IBL), visualization and modeling. A teaching module on this topic was prepared which included a student workbook and a teaching manual for junior secondary school students. An action-based methodology was employed and student performance was measured using formative and summative testing. Student input was obtained on the learning issues experienced by them via interviews and repertory grid analysis based on Kellyian Personal Construct Psychology principles. Initial results point towards a better comprehension of PNM by the intervention group as opposed to their control group peers. Repertory grid analysis was used to highlight and rank aspects of their affective and cognitive learning experiences. This approach has enabled the systematic metering of student comprehension of chemistry constructs and served to detect the learning gaps in the construct hierarchy encountered by the learners.

FOCUS OF STUDY

McElwee (2010, p.249), states "In the past, there was an undue emphasis on 'knowledge as content' rather than knowledge as a set of thinking skills". The introduction of new curricula, such as iRELAND'S Junior Certificate Science with its emphasis on inquiry, attempted to address this issue. However, while the curriculum changed, there is concern that the newer teaching methods required were not easily adopted by all teachers. In this study, the researcher explores a change in his teaching pedagogy from a mainly deductive style to using an inquiry-based approach, merged with a modelling and visualisation, to see if it improves the knowledge of first year Junior Certificate science students in the area of the PNM.

LITERATURE REVIEW

The particulate nature of the matter (PNM) is rated by several authors as significant for students long-term success in the pursuit of chemistry, including Ozmen (2011), de Vos and Verdonk (1996), Taber (2001), Snir, Smith and Raz (2003), Liu and Lesniak (2004), Taber (2005), Othman (2008), Adbo (2009) and Newman (2012). In fact, Valdines (2000) saw fit to claim to an appropriate understanding of the particulate nature of matter is essential to the learning of chemistry.

However, Othman (2008) points to several studies (e.g. Albanese & Vicentini, 1997; Ben-Zyi, Eylon, & Silberstein, 1986; Johnson, 1998; Nakhleh et al., 2005), indicating that students' understanding of this model of matter is relatively limited. Childs and Sheehan's (2009) study on Chemistry topics that students at all levels find difficult detail many topics at Junior Certificate level in Ireland with which students struggle. Interestingly, the majority of these topics relate to the area of PNM.

Inquiry Based Learning (IBL)

The National Science Education Standards (NSES) (NRC, 1996, p.2) describe scientific inquiry as "the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work".

The European Commission (2007, p.9) indicate that the 'bottom up' or student centered, inductive approach to teaching science is now mostly referred to as Inquiry-Based Science Education. They cite Linn, Davis and Bell (2004) in describing Inquiry-Based Science Education (IBSE) as:

> *...the intentional process of diagnosing problems, critiquing experiments, and distinguishing alternatives, planning investigations, researching conjectures, searching for information, constructing models, debating with peers, and forming coherent arguments.*

Inquiry-based teaching has been promoted over deductive teaching by Anderson (2002), Llewellyn (2005), Gyllenpalm, Wickman and Holmgren (2010) Bridel and Yezierski (2012) with a view to developing skills of comprehension, learning, critical and creative thinking. Hmelo-Silver, Ravit and Clark (2007) refer to this process as 'sense making'. Sadeh and Zion (2009) also view IBL's main purpose as the guidance of students to construct their own knowledge which is echoed by Oliveira (2010).

Furtak (2006, p.454) suggests that it may be useful to think about scientific inquiry as one side of a continuum of different methods of science teaching. At one pole of the continuum is traditional didactic teaching while at the opposite pole, is teaching to an open inquiry approach. This is reflected in Figure 1.

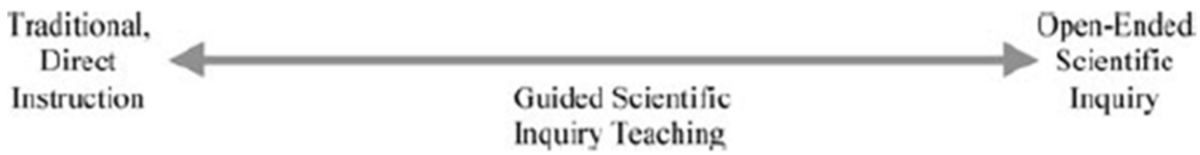

Figure 1: Continuum representing forms of Science Instruction (Furtak, 2006 p 454)

Modelling and Visualisation

According to the literature, modeling is subsumed by visualization. In recent times, Mayer and Moreno (2002), Jones, Jordan and Stillings (2005), Sweller (2005), Waldrip, Prain and Carolan (2006) and Chang, Quintana and Krajcik (2009) advocated the use of physical models, workbooks, computer models and personal modeling. Penner et al. (1997) and Harrison and Treagust (1998) gave modelling their fullest endorsement by claiming that modern chemistry cannot be taught without models.

Personal Construct Psychology

This is an optimistic psychology based on constructive alternativism (Kelly, 1955). The approach of Kelly is used in discerning views of subjects as they participate in learning, training and developmental projects. Repertory grid constructs have been applied to business and educational issues (Pope and Watts 1988) and have a role to play in refining the focus of individuals groups and programs.

RESEARCH DESIGN AND METHODS

Action Research with Personal Construct Psychology as an adjunct was used in carrying out the research methodology.

McNiff and Whitehead (2006, p.27) cite Berlin (1998) to indicate that action researchers need to make the following assumptions regarding knowledge:

- Knowledge is created, not discovered, in a process which often involves trial and error.
- All answers are tentative and open to modification.

To this end, the literature was used to inform the creation of a pedagogical instrument in the form of a workbook. The workbook itself was further developed by reflecting on the learners' difficulties in class while working with it. These were noted in a reflective journal. Furthermore, exam answers given by students were analysed and taken into account annually in an iterative process with the aim of optimizing the learning experience of the students. Repertory grid interviews were conducted with students to see if the pedagogical approach (mixture of structured and guided IBL with modeling and visualization techniques) can give the students a positive experience so they can elaborate their construct systems in a 'learning of science' context. In order to do this, it was important to see how students construed themselves as scientists and also how they construed the pedagogical tool (the workbook developed for the study) that was used to promote the form IBL used. This allowed for the acknowledgement of the views of the students in a way that can inform the modification of the pedagogical tool.

SUMMARY OF PRELIMINARY RESULTS

Figure 1 below indicates the % of the intervention (Int) and control (Cont) group that got each question completely correct on the test.

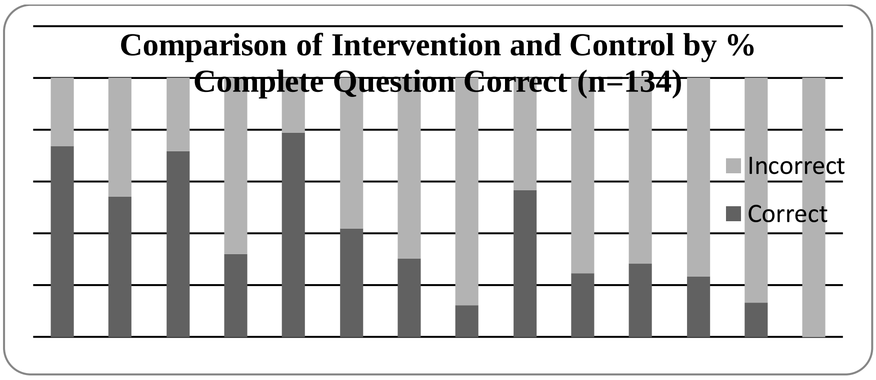

Figure 1: Percentage of Intervention Group who got Complete Questions Correct

The comparison enjoys statistical significance in all but one question (question 6).

PCP as a Navigational Aid to Quantitative Analysis and To Measure Learning Gaps (One example with respect to Question 1)

Question One

1. A blown up balloon with 5g of air in it was brought into a room to help decorate it for Martina's birthday. The balloon burst and the air inside was released into the room. The room

already had 1,650g of air in it – did anything happen to the mass of the air in the room. Explain if you think something did.

Table 1: Chemical Concept Construct System Evident From Analysis of Student Data

Superordinate Construct: Students were able to convey a specific quantitative understanding of the conservation of mass.	
Bipolar Subconstructs	
Student has displayed scientific protocol and detail within their answer.	Student has displayed a lack of acknowledgement of scientific protocol or detail within their answer.
Student understands the additive nature of the process and can convey it qualitatively and quantitatively.	Student understands the additive nature of the process but portrays a mainly qualitative understanding.
Student understands diffusion and gives some qualitative and quantitative detail.	Student appears to understand diffusion and gives some qualitative detail but lacks any quantitative perception.
Additive nature of process recognized because they are have an understanding of the law of conservation of mass.	Additive nature of process not recognized because they are likely to have a partial understanding of the law of conservation of mass.
Student understands the law of conservation of mass.	Student has no understanding of the law of conservation of mass.

PCP AS A NAVIGATIONAL AID TO QUALITATIVE DATA

Preliminary findings are presented in terms of two constructs (below) of 'How I see myself as a scientist' in relation to the scientists presented to students as elements in the repertory grid interviews (Gallilleo, Frankland and Fleming). Constructs of 'How I see the pedagogical tool' regarding the workbook that was developed to support IBL are not presented here but are implicitly linked to those shown here.

Note: The outcome of student self-perception are shown below each construct.

Loved what they did –-- Did science for money

Currently, students see themselves as being quite close to the pole 'loved what they did' and *ideally see themselves as being even closer to it*. It is also at this pole where they see scientists.

Confident –---Did not believe in what they did

Students perceive scientists to be at the 'confident' end of the pole of this construct. At the moment they see themselves as being mainly near this pole but some are in the middle. *The respondents almost entirely see themselves as ideally at the 'confident' pole of the construct*.

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Experience with Inquiry Activities and their Assessment at a Lower Secondary School in Slovakia

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The education in science at lower secondary schools in Slovakia has changed a lot in last few years. The number of compulsory lessons has been reduced, however the emphasize is put on active learning of pupils. The textbooks are based on this approach and inspite of the shortage of lessons teachers are trying to guide the lessons in an interactive way implementing elements of inquiry. Under the running system of continuous teachers´ education many enthusiastic teachers take part at teacher training courses in order to educate themselves in this field. Teachers usually implement or adapt inquiry activities that are already prepared or they even develop their own ideas into the activity according to the needs of their class. The contribution presents examples of inquiry activities designed by a physics teacher of one of the Slovak lower secondary schools. Activities are developed for the use in the class or within a study visit of a research institute emphasizing an authentic scientific experience. The examples of activities involve: How chocolate melts, Human and horse hairs are, How crystals grow, How noisy is our school, Heat, heat conduction, Which objects conduct electric current. There are different elements of inquiry to follow and also assessment tools recommended for the activities to evaluate.

INTRODUCTION

Teaching physics at lower secondary schools has changed a lot since 2009 in Slovakia when the educational reform started to be implemented across all the schools in the country. The reform implies a two-level model of Slovak schools control. The state curriculum defines the basic principles and goals of education based on the general Slovak educational policy while the school curriculum gives schools an opportunity to fit the interests of the particular school and its pupils. The spiral way of building knowledge and skills has been replaced by teaching blocks of topics that are strongly supported by activities aimed at developing experimental skills of pupils, in 6th and 7th grade, in particular. The physical laws and abstract physical formulas are introduced in 8th and 9th grade only, since at this level students get known about how to solve equations in mathematics.

There were a number of new textbooks developed. They are full of different experimental activities with a lot of inquiry elements involved to carry out at schools as well as at home that helps a lot to increase pupils´ interest and motivate them towards science. The activities result in developing theoretical knowledge about the phenomena that pupils gradually get familiar with as well as inquiry skills connected with the way how to get to the target. The education in physics at this level is based on:

- Observation of everyday phenomena (school or home observations) and their explanation,
- Predictions what can happen and what happens next when exploring phenomena, objects and their properties,
- Experimentation, evaluation of experiments,
- Exploring other relationships and applications of phenomena

- Drawing conclusions.

HOW WE IMPLEMENT AND ASSESS IBSE AT LOWER SECONDARY LEVEL

In order to follow the goals of the reform the Basic school Kežmarská, Košice tries to carry out activities that support the ideas of IBSE. Except from the textbook inquiry activities we have adapted, developed and successfully carried out a lot of additional activities in cooperation with science institutions as well as pupils own project work and moreover, we have arranged special science events, e.g. science open day for parents, science lesson for elementary school pupils, science conference at school or at science institution (Slovak academy of Science and University). The assessment of pupils work within these activities has been based on the following ideas:

- attitude towards the inquiry activity, enthusiasm and drive,
- ability to work in a group: teamwork and cooperation,
- level of knowledge and their skills to plan investigation and gain and process data from the experiment and search for information,
- skills to present information and explain knowledge in front of different audience (class, parents, younger students, scientists from institutions).

EXAMPLES OF INQUIRY ACTIVITIES AND ITS ASSESSMENT

How to melt chocolate

This is an example of home assignment. The goal is to find the best way to melt chocolate and find out the melting point. The designed experiment should have been complemented with the written report involving conclusions. In this case we have decided to make a peer assessment. Pupils that did not know the names of their assessed friends were asked to judge: tools and materials chosen, the designed procedure, explanation, originality with each item assessed with maximum 5 points.

Figure 1: Examples of pupils written reports in chocolate experiment complemented with peer assessment (in yellow circles).

Human and horse hair

This activity has been carried out in cooperation with the Institute of Physics, Slovak Academy of Science. There were 15 7th and 8th grade pupils participating. In the first part the human hair has been investigated. The physicists explained the way how the hair DTA analysis is done when the hair is heated. Pupils were exploring the shape of a human hair and its thickness with the help of a microscope and were measuring its strength, load capacity and elongation under different applied forces. In the second part the horse hair has been explored and its properties compared with those of a human hair. The results of measurements have been elaborated by groups of pupils preparing the final presentation for the science conference. The pupils work on the project was assessed on the basis of pupils´ attitude to work, their interest towards the project and work with the apparatus and measuring tools, cooperation within the group, searching additional information from various sources and the level of presentation and argumentation within the discussion at the science conference.

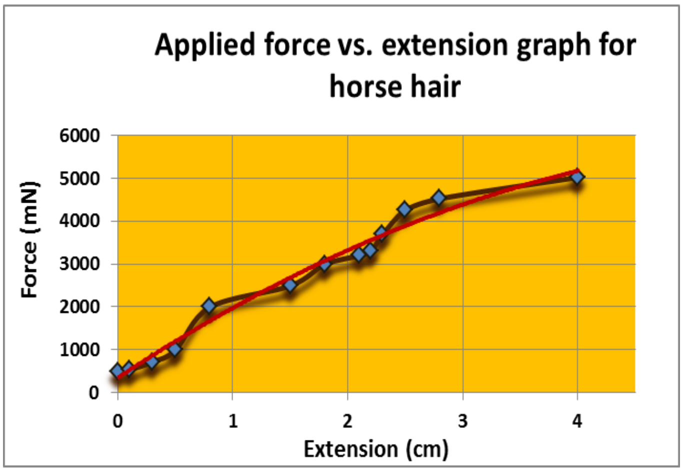


Figure 2: Pupils investigating the hair properties and an example of horse hair measuring results

How crystals grow

This activity has been carried out in cooperation with the Technical University. About 90 6th grade pupils have already participated on this project since 2007. The project usually involves four parts. Its first part is aimed at the study visit of the University mineralogical collection. Secondly, in the school laboratory, pupils create their own different colour crystals made by evaporating saturated water salt solutions (e.g. copper sulphate, potassium ferricyanide, nickel sulphate, sodium chloride). Then they investigate their properties (shape, crystalline structure, colour, etc.) and complement their observations with information gained from different sources. Finally pupils present the results of their work in a form of a presentation at pupils' science conference.

In order to assess pupils work we use teacher assessment. Teacher observes pupils attitudes and their involvement and interest during the study visit that always attract pupils' attention. However, the laboratory activity is not so attractive for pupils and usually just a small group works together in order to mix solutions and observe what happens. However, the last year's pupils were working so enthusiastically that they were awarded by the school trip to Kremnica and Banská Štiavnica. Kremnica is one of the oldest mints in the world. Coins have been still minted there not only for Slovakia but also for other foreign countries. Banská Štiavnica is an old historical mining town with an interesting mineralogical museum and old mining tunnels.

Figure 3: Examples of the crystals´ activities

How noisy is our school

In the years 2011-13 there was a reconstruction of the school performed. Parts of the building were torn down and rebuilt; nevertheless, teaching went still on even in such an annoying and uncomfortable environment. The noise was so unpleasant that it gave reason to investigate its level and its negative effects and additionally, to explore the noise at home created by home appliances, e.g. washing machine, refrigerator, TV or elevator and also the noise in the supermarket, street and means of transport. Different groups of pupils were exploring different places using the sound level meter. Their project work resulted in interesting presentations shared with the audience at the science conference. The project work evaluation was based on the pupils´ creativity, originality in exploring different noise environments, objects, and work with internet resources, tabular and graphical evaluation of the noise level, suggestions on protection against noise and the level of pupils´ presentations.

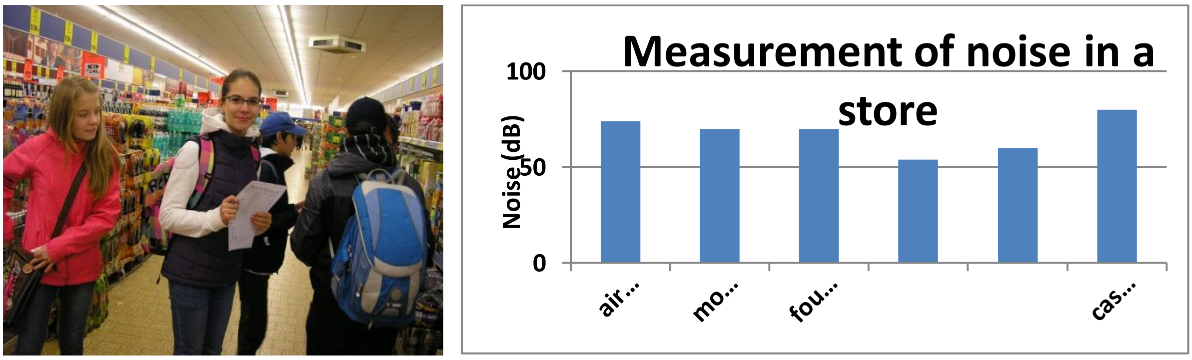


Figure 4: Pupils recording data in the store and examples of measuring results

Heat, heat conduction

This activity has been carried out by the whole class at school. It was aimed at heat exchange between the hot and cold water. Firstly pupils were expected to draw a concept map on the topic of heat in order to think about all the possible concepts connected with heat. Secondly, they designed an experiment in order to investigate the heat exchange between hot and cold water taking into account different conditions and their influence on the experimental results (open or closed vessel, heat dissipation by a vessel, design of the best calorimeter). Based on the plan pupils carried out experiments mixing together same or different amount of water predicting their final temperature and comparing their prediction with the experimental result.

After the activity the written reports were collected and the assessment was done by the teacher using 4-scaled rubrics. In fig. 5 there is an example of a very rich concept map involving many terms like e.g. heat transfer – convection, conduction, radiation, thermal conductors (metal, spoon), thermal insulators (Styrofoam, thermos flask), temperature, thermometer, bimetal, alcohol, mercury thermometer, units, Celsius, Kelvin, Fahrenheit, etc. (4 points). The fig. 6 presents a design of an experiment on heat exchange between hot and cold water. The pupil describes different parameters that should be thought about when carrying out the experiment, e.g. vessel (material, open or closed, insulation, and best calorimeter), initial water temperatures and masses and where the vessel is situated (on metal, wooden or plastic plate). He also suggests the experimental procedure.

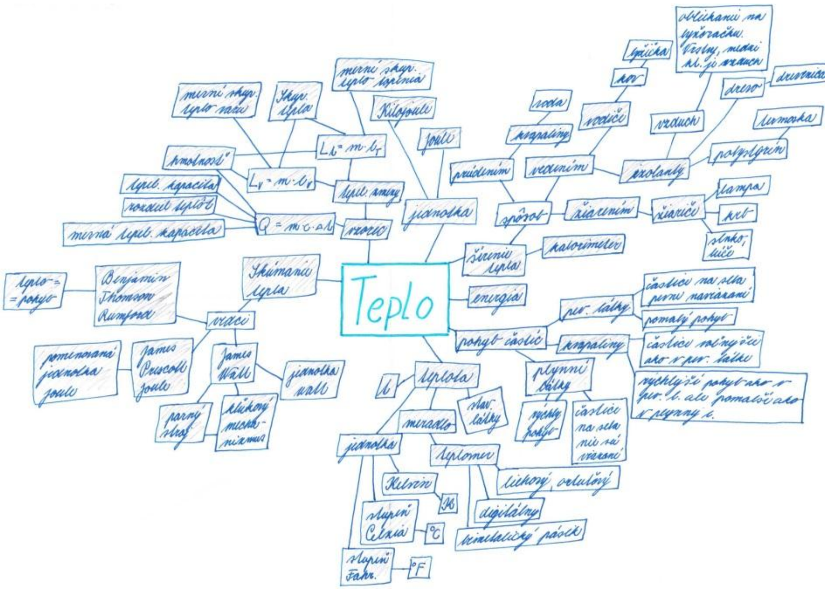
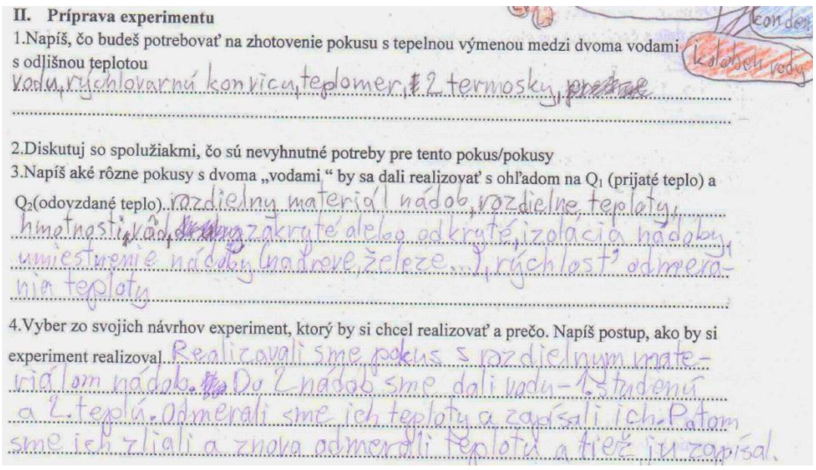


Figure 5: Example of the very rich concept map involving a lot of terms.



II. Príprava experimentu

1.Napíš, čo budeš potrebovať na zhotovenie pokusu s tepelnou výmenou medzi dvoma vodami s odlišnou teplotou vodu, rýchlovarnú kanvicu, teplomer, 2 termosky,

2.Diskutuj so spolužiakmi, čo sú nevyhnutné potreby pre tento pokus/pokusy

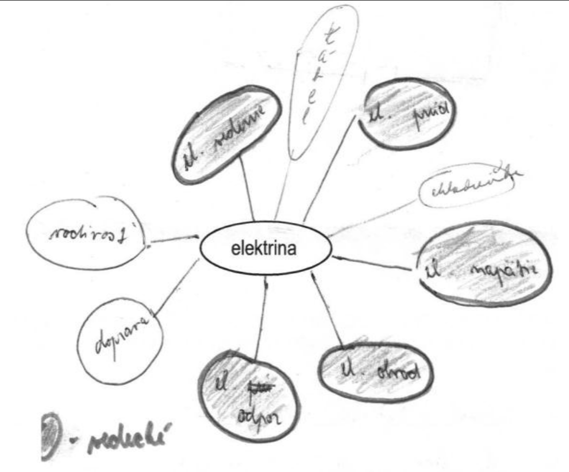
3.Napíš aké rôzne pokusy s dvoma „vodami " by sa dali realizovať s ohľadom na Q_1 (prijaté teplo) a Q_2(odovzdané teplo) rozdielny materiál nádob, rozdielne teploty, hmotnosti vôd, zakryté alebo odkryté, izolácia nádoby, umiestnenie nádoby (na dreve, železe...), rýchlosť odmerania teploty

4.Vyber zo svojich návrhov experiment, ktorý by si chcel realizovať a prečo. Napíš postup, ako by si experiment realizoval Realizovali sme pokus s rozdielnym materiálom nádob. Do 2 nádob sme dali vodu - 1. studenú a 2. teplú. Odmerali sme ich teploty a zapísali ich. Potom sme ich zliali a znova odmerali teplotu a tiež ju zapísal.

Figure 6: The planning of experiment

Which objects conduct electric current

The activity consisted of several stages, i.e. developing a concept map on electricity, designing an experiment on electrical conductivity, selecting available materials, formulating hypotheses on conductivity of different objects, conducting an experiment, drawing conclusions on conductivity and writing an essay on pros and cons of electric current based on searching for information. Based on the written report each part was separately assessed by teacher using 4-scaled rubrics. The examples in fig. 7 involves a concept map with just a few related concepts (1 point) and hypothesis on conductivity (conducts well, poorly, not at all) of different objects (tea spoon, dice, pen, piece of wood, screw, stone, plastic, scissors, graphite, piece of glass, button, etc.) explored experimentally (4 points).



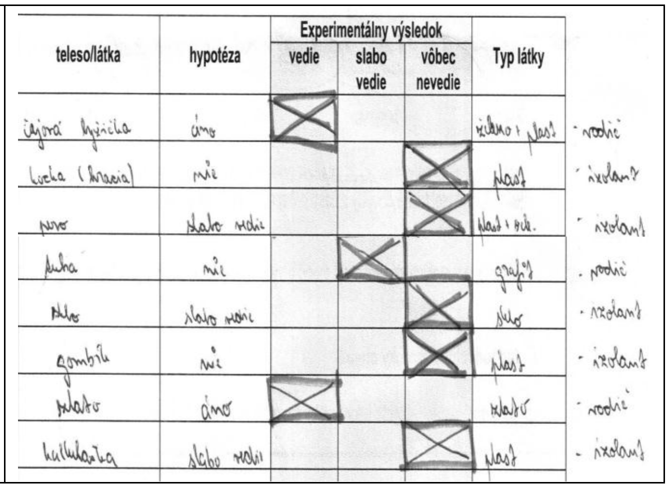


Figure 7: Example of the concept map (left) and hypotheses on conductivity of different objects (right)

CONCLUSION

The IBSE activities are the integrated part of physics education at lower secondary schools in Slovakia. The current curriculum as well as the textbooks is based on this approach. We are trying to carry out and involve pupils into different kinds of inquiry activities that are often enhanced by study visits to research centres, trips and excursions connected with the science topic. At the end we always expect outputs from our pupils presented in different forms (written reports, oral presentations, etc.) However, the evaluation of this kind of activities is usually not straightforward and easy. Our experience is that pupils are expecting and are used mainly to summative assessment with a final grade given by the teacher corresponding to his performance. Gradually, we are trying to implement formative assessment in many forms, not only teacher but also peer and self-assessment. Using the latter ones pupils learn to be critical but fair and respectful. Sometimes these forms of assessment motivate pupils towards the consistent and effective learning even more than traditional summative assessment tools.

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A Comparison of TIMSS 2011 and PISA 2012 mathematics frameworks and performance for Ireland and Selected countries

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Irish schools recently participated in two major international surveys of mathematics achievement – TIMSS 2011 and PISA 2012. These two surveys originate from different philosophies of mathematics education as reflected in their assessment frameworks and tests. This paper compares the two mathematics frameworks in terms of mathematical content and cognitive processes and in terms of the test results, particularly at the level of performance subscales, in the context of Irish mathematics curricula and results for selected countries including UK and Northern Ireland. Some concerns arising from this analysis are discussed along with recommendations which could inform curriculum review.

INTRODUCTION

In 2011, Ireland participated in the Trends in International Mathematics and Science (TIMSS) Study, which is organised every four years by the International Association for the Evaluation of Educational Achievement (IEA). Whereas TIMSS is offered at both Fourth and Eighth grades (equivalent to Fourth class at primary level in Ireland, and Second year at post-primary level), Ireland participated at Grade 4 only. However, students in Grades 4 and 8 in Ireland will take part in the next TIMSS study in 2015.

In 2012, Ireland participated in the Programme for International Student Assessment (PISA), which is organised by the Organisation for Economic Cooperation and Development (OECD). Unlike TIMSS, PISA uses an age-based sample (students aged 15-years), which cuts across grade levels (Second to Fifth year in Ireland, with a majority of students in Third year).

PISA 2012 was the fifth cycle of PISA in which Irish 15-year olds participated. In the first three cycles (200, 2003, 2006), students in Ireland achieved mean scores on paper-based mathematics that were not significantly different from the corresponding OECD country averages. In 2009, Irish students achieved a mean score that was significantly below the OECD average, suggesting a decline in achievement between 2009 and earlier years. However, in the Irish national report on PISA 2009 (Perkins *et al.*, 2012), it was suggested that low student engagement and factors associated with the scaling of achievement were responsible for the lower performance. In 2012, students in Ireland performed on paper-based mathematics at a level that was significantly higher than the OECD average (Perkins *et al.*, 2013). On a computer-based assessment of mathematics, also administered in 2012, students in Ireland achieved a mean score that was not significantly different from the corresponding OECD average. Thus, students in Ireland did less well on computer-based mathematics in 2012 (the first time computer-based mathematics was included in PISA) than on paper-based mathematics. Mathematics was assessed as a major assessment domain in PISA in 2003 and 2012. This means that PISA included a larger than normal proportion of mathematics items, and that performance on PISA mathematics was reported both in terms of overall performance and of performance on content and process subscales.

A majority of students who participated in PISA 2012 in Ireland were in Third year, and had not studied under the Project Maths curriculum (e.g., Department of Education and Skills, 2015), which was introduced in 24 pilot schools in 2008, and in First and Fifth years in all other schools in 2010. In future PISA cycles, all students in Ireland will have studied the Project Maths curriculum, which places a greater emphasis on understanding of mathematics, and the solving of mathematical problems in real-life contexts, than its predecessor, the pre-2010 Junior Certificate mathematics syllabus (Department of Education, 2000).

DEFINITIONS AND STRUCTURE OF TIMSS AND PISA MATHEMATICS

PISA refers to mathematics as mathematical literacy, and defines it as:

> an individual's capacity to formulate, employ, and interpret mathematics in a variety of contexts. It includes reasoning mathematically and using mathematical concepts, procedures, facts and tools to describe, explain and predict phenomena. It assists individuals to recognise the role that mathematics plays in the world and to make the well-founded judgments and decisions needed by constructive, engaged and reflective citizens (OECD, 2013, p. 25).

Clearly, PISA is concerned with students' knowledge of mathematical facts and their ability to use mathematical tools, on the one hand, and with their ability to apply mathematics to real-life situations on the other. Although TIMSS does not provide a direct definition of mathematics, the following statement appears in the TIMSS 2011 assessment framework:

> A prime reasons for having mathematics as a fundamental part of schooling include the increasing awareness that effectiveness as a citizen and success in a workplace are greatly enhanced by knowing and, more important, being able to use mathematics (Mullis *et al*., 2009, p. 19).

Hence, TIMSS is also concerned with mathematics is it relates to future citizenship and participation in adult life. However, the framework also illustrates how TIMSS seeks to establish relationships between the intended curriculum, the implemented curriculum, and the attained curriculum. This implies that TIMSS gathers information about curriculum, and seeks to establish relationships between the TIMSS mathematics test and the curricula of participating countries, as well as between classroom instructional factors and student performance in mathematics. Hence, TIMSS tends to be viewed as a curriculum-based assessment of mathematics, and PISA as an assessment of the mathematics required for future life and education.

The content areas and processes underlying TIMSS mathematics are those typically associated with traditional school-based mathematics. The content areas are Number, Algebra (Grade 8 only), Geometry, and Data & Chance (Table 1). These are quite similar to the content areas found in Project Maths, but quite different from those in PISA. It is particularly noteworthy that PISA does not include an explicit Algebra strand. While it might be assumed that there is a direct correlation between PISA Space & Shape and Geometry (and Trigonometry), this turns out not to be the case. For example, Close (2006) found that none of the PISA 2003 Space & Shape items mapped onto the Geometry or Trigonometry content areas in the pre-2010 Junior Certificate syllabus. This indicates that PISA Space & Shape, which focuses on spatial reasoning and applied problem solving, has a quite different focus from more traditional, theorem-based content area of Geometry and Trigonometry.

Table 1: Content and Processes in TIMSS, PISA and Project Maths Frameworks

	TIMSS	PISA	Project Maths
Content	Number	Change & Relationships	Number
	Algebra*	Shape & Space	Algebra
	Geometry**	Quantity	Geometry & Trig.
	Data & Change***	Uncertainty	Functions
			Stats & Probability
Processes	Knowing	Formulating	Recall ****
	Applying	Employing	Instrumental Understanding
	Reasoning	Interpreting	Relational Understanding
			Solving Problems
			Developing Analytic & Creative Powers
			Appreciation of & Positive Attitudes towards Maths

*Not included at Grade 4; **Geometric Shapes & Measures at Grade 4; ***Data Display in Grade 4. ****Although not stated in the syllabus, underlying processes can be inferred from the statement of aims.

Sources: Mullis et al. (2009), OECD (2013), Department of Education and Skills (2012)

It is perhaps in the area of mathematical processes that TIMSS and PISA frameworks differ most from one another. The processes underpinning TIMSS are Knowing, Applying and Reasoning. Again, these are broadly similar to those underpinning Project Maths (Recall, Instrumental Understanding, Solving Problems, Relational Understanding), but are quite different form PISA, which draws on mathematical modelling as the source of its process categories (OECD, 2013). In this view, the problem solver begins with a problem in a real-world context and *formulates* the problem mathematically, according to the concepts and relationships identified. The problem solver then *employs* mathematical concepts, procedures, facts and tools to arrive at a mathematical solution. This stage typically requires reasoning, manipulation, transformation and computation. Finally, the problem solver *interprets* the mathematical results in terms of the original problem. The use of stages of mathematical modelling as a basis for categorising mathematical processes is new, and its validity has yet to be established. It is unclear at this time whether it can serve as a framework for understanding mathematical thinking, or indeed organising instruction.

RESEARCH COMPARING TIMSS AND PISA MATHEAMTICS

A number of studies have directly compared TIMSS and PISA mathematics, focusing on differences between the frameworks, and differences in performance across countries that have participated in the two studies.

In their comparison of TIMSS and PISA, Ruddock *et al.* (2006) noted that:

- TIMSS emphasises items which require the reproduction of facts or standard algorithms, while PISA focuses on items which demand connections with existing knowledge.
- TIMSS has a larger number of items focusing on Number and Measurement, while PISA items are more evenly spread across their content domains.
- A majority of TIMSS items are multiple choice, while a majority of PISA items are constructed response.
- While TIMSS mathematics items tend to be independent of one another, PISA items include multiple questions based on one stem (problem context)

Ruddock *et al*. note that, while TIMSS and PISA both contain complex language, PISA also has a heavier reading load. They note that the high reading demand of PISA items is often accompanied by a relatively low demand in the mathematics required, reflecting the lower level of mathematics that students can apply in new contexts as opposed to the more familiar ones they encounter in, for example, TIMSS. Wu (2009) also acknowledges that there is a considerable amount of reading in PISA, compared with TIMSS, and speculates that, in countries where reading achievement is relatively higher, students may be exposed to an environment which supports the use of mathematics problem-solving skills in everyday life.

Performance on TIMSS and PISA can be compared at country and item levels. Figure 1 provides a comparison between countries that participated in TIMSS 2011 at Grade 8 and in PISA 2012 (Ireland is not included as it did not take part in TIMSS 2011 at Grade 8). The figure shows that Asian countries Singapore, Hong Kong-China, Chinese-Taipei, Korea and Japan are the five highest-ranking countries in both assessments. On the other hand, a number of non-Asian countries, such as the Russian Federation, the United States, Lithuania and Hungary, perform better on TIMSS than on PISA, while countries such as New Zealand and Norway do marginally better on PISA. And, finally, a number of countries perform at about the same level in both studies, including Australia, Slovenia and Turkey. The country-level correlation between mean scores on TIMSS 2011 (Grade 8) and PISA mathematics is 0.93.

Wu (2009) compared the performance of students in selected Asian (Hong-Kong, Japan, Korea) and Western countries (Australia, England, United States) on specific TIMSS Grade 8 and PISA items. She noted that, at individual item level, Western countries may be at an advantage in PISA, where more items are embedded in real life contexts. Related to this, she argues that Western students may approach PISA problems using a practical, common-sense approach, compared with students in Asian countries, who may adopt a more theoretical stance.

The foregoing will be of interest in terms of looking ahead to the performance of students in Ireland on TIMSS 2015. Second-year students in TIMSS 2015 in Ireland will have studied the Project Maths syllabus, with its emphasis on mathematical understanding and on solving mathematical problems embedded in real-life contexts, which one might expect could convey an advantage on PISA-style items. On the other hand, they will also have studied more traditional mathematics content in Project Maths, including a theorem-based or synthetic approach to Geometry, which might be conductive to doing well on TIMSS.

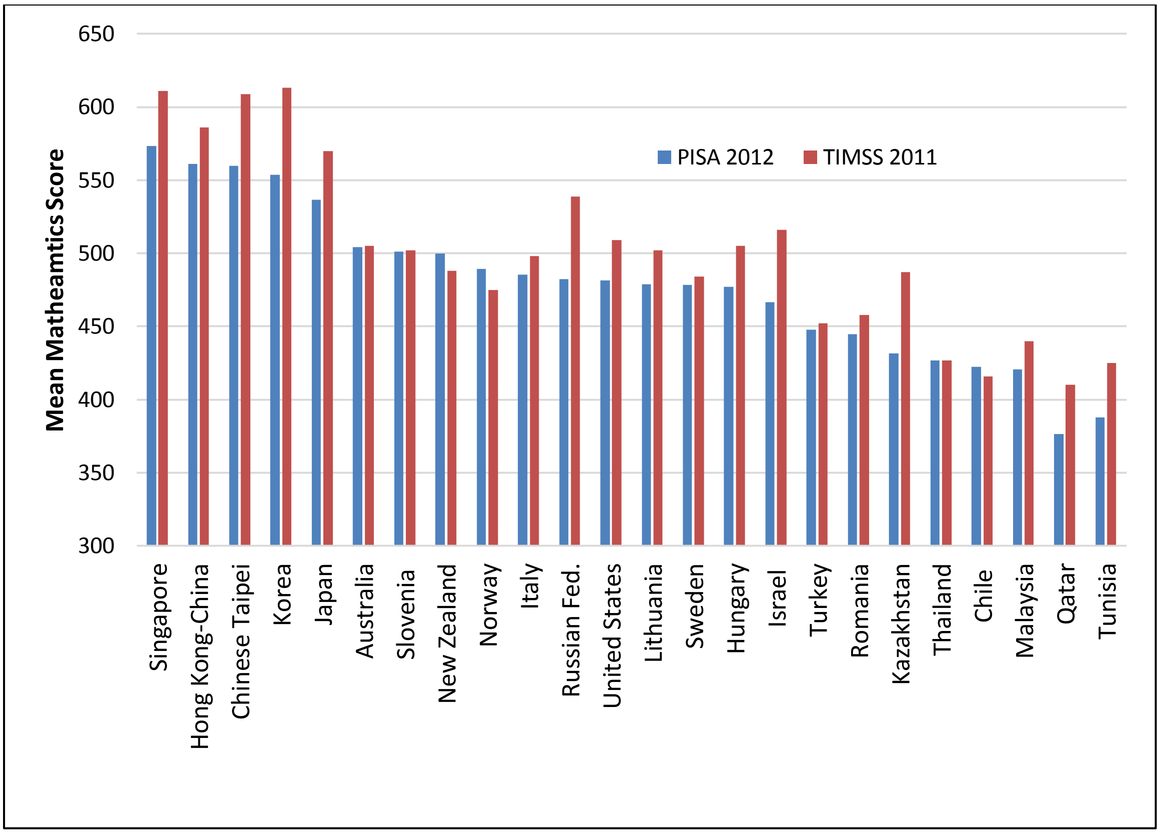


Figure 2: Comparison of Country-Level Performance on TIMSS 2011 (Grade 8) and PISA 2012

IRELAND IN TIMSS AND PISA

Although data for Ireland on TIMSS 2011 Grade 8 mathematics are not available, we can draw some broad conclusions about the performance of students in Ireland based on their performance on TIMSS 2011 Grade 4 mathematics and PISA 2012 mathematics at age 15, relative to other countries in both assessments. Figure 2 shows the relative rankings of countries that participated in both assessments. The figure again shows that Asian Countries – Singapore, Hong-Kong China, Chinese Taipei, Korea and Japan – were the highest-ranking countries in both studies, suggesting that the foundations for strong performance at age 15 on PISA mathematics may be established by the middle of primary schooling. It is also noteworthy that Ireland performed at about the same level on PISA (11th) as on TIMSS (13th), among countries in both studies. However, a number of countries show quite different rankings across the two studies, including Poland (8th in PISA, 29th in TIMSS), the Russian Federation (7th in TIMSS, 20th in PISA), and the United States (8th in TIMSS, 22nd in PISA).

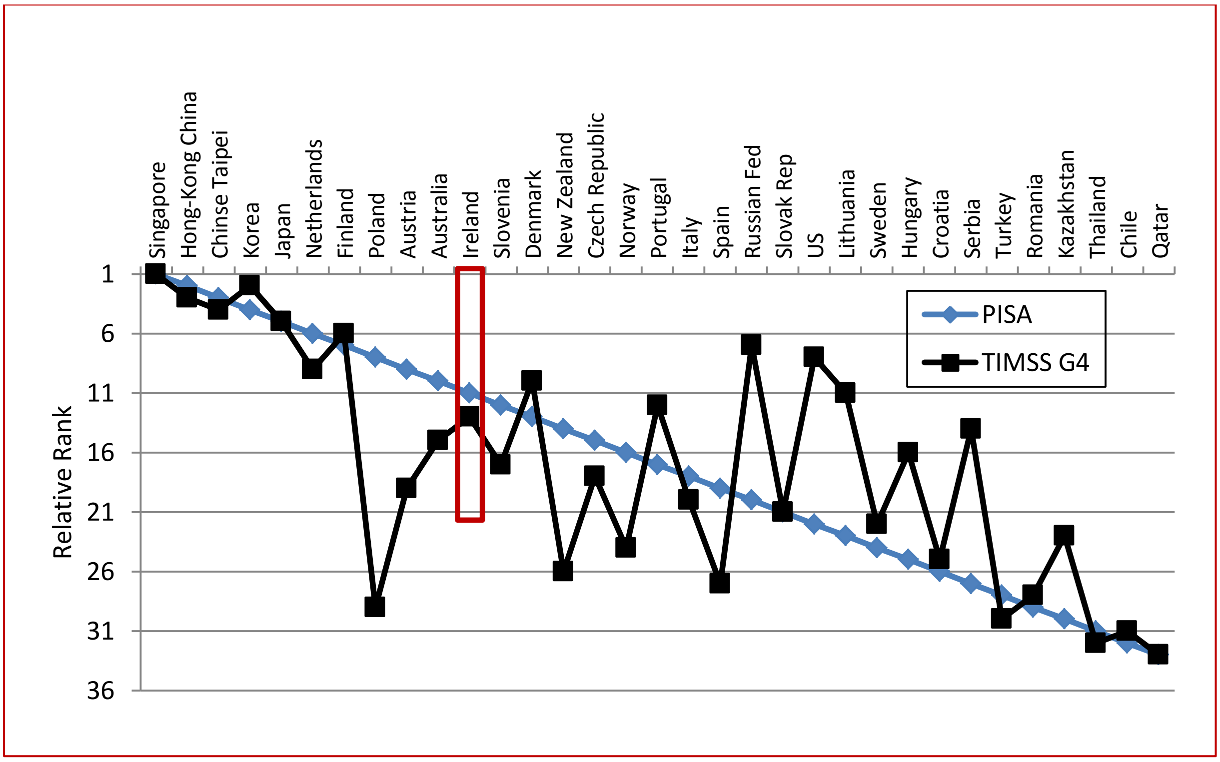


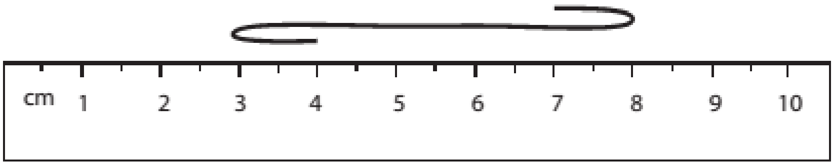
Figure 3:Relative Rankings of Countries in TIMSS 2011 (Grade 4) and PISA 2012

In addition to data on overall performance in mathematics, TIMSS and PISA provide data on performance by content area and process. In TIMSS 2011 (Grade 4), students in Ireland performed at a level that was significantly above their overall score on Number (difference = + 4 scale points), and at a level that was significantly below their overall score on Geometric Shapes & Measures (-7) and Data Display (-4) (Eivers & Clerkin, 2012; Mullis *et al.*, 2012)). On the TIMSS process skills, students in Ireland achieved at a level that was significantly higher than their overall score on Knowing (+12), and at a level that was significantly below this on Reasoning (-18). There was no difference between performance on Applying and overall performance. Hence, TIMSS suggests a relative weakness on Geometric Shapes & Measures, on Data Display, and on Applying.

The overall performance of students in England (542) and Northern Ireland (562) was significantly higher than in Ireland (527) on TIMSS mathematics. Like students in Ireland, students Northern Ireland did better on Number (+4), and less well on Data Display (-8), compared with their overall performance. They also did better on the Knowing process (+17), and less well on Reasoning (-25), than on the test as a whole, with no difference on Applying. Students in England did less well on Number (-3), and better on Data Display (+7) than on the test as a whole. They also did better on Knowing (+10), and less well on Reasoning (-11), with no difference on Applying. While most TIMSS 211 countries tended to do less well on Reasoning than on the test as a whole, students Australia, Finland and Korea performed at the same level on Reasoning as on the test as a whole.

Analyses of TIMSS data at the individual item level (Close, 2013) suggest that there are gaps in the mathematical knowledge of students in Ireland. For example, on an item requiring students to select the length of a piece of string (Figure 3), just 16% of students in Ireland provided a correct response, compared with an international average of 28%. Given the relatively strong emphasis on estimating length in the Primary School Mathematics

Curriculum in Fourth class (NCCA, 1999, one would have expected a stronger response from students in Ireland. Other items on which students in TIMSS 2011 in Ireland did not do very well included one involving rotation as a geometric transformation (which was on the pre-1999 mathematics curriculum, but no longer features), one involving identification of the factors of 12, one involving basic multiplication (23 X 19) and one involving distance and time (speed).



If the string in the diagram above is pulled straight, which of these is closest to its length?

Ⓐ 5 cm

Ⓑ 7 cm

Ⓒ 8 cm

Ⓓ 9 cm

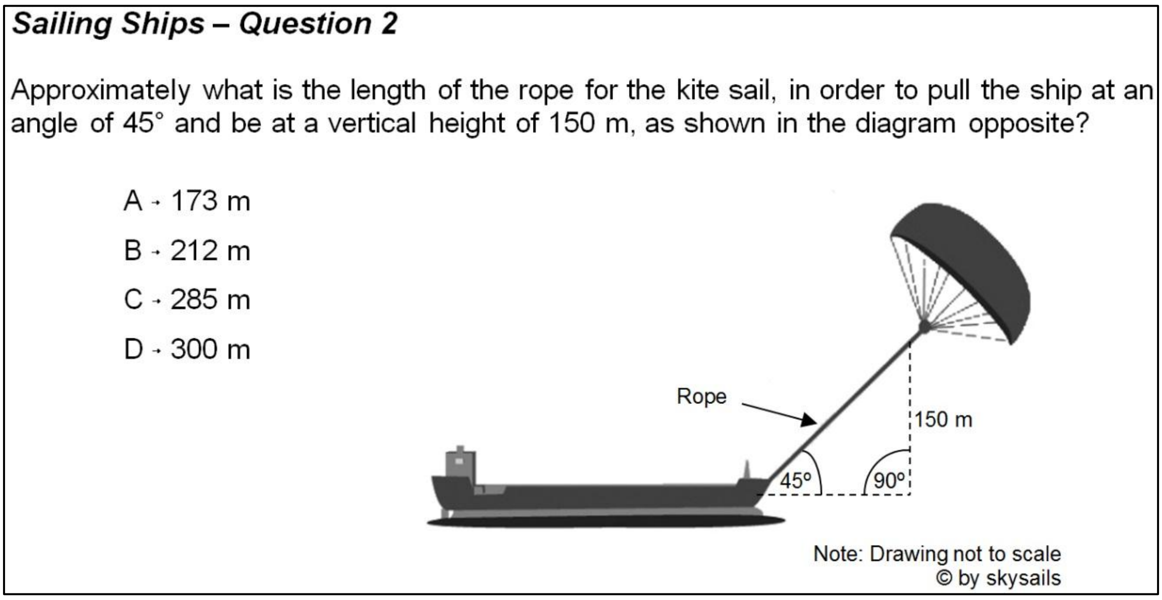
Correct:	Ireland: 16%	International: 28%

Figure 4:Sample TIMSS 2011 (Grade 4) Item

On PISA 2012, students in Ireland achieved mean scores that were above the corresponding OECD averages on three mathematics content areas – Change & Relationships, Quantity, and Uncertainty & Data. On the fourth – Space & Shape – students in Ireland achieved a mean score that was significantly below the OECD average. In relative terms, performance in Ireland was strongest on Uncertainty & Data (mean score = 509), and weakest on Space & Shape (478). Female students in Ireland performed particularly poorly on Space & Shape. On the PISA process subscales, students in Ireland achieved mean scores that were significantly above the corresponding OECD averages on Employing and Interpreting. Performance on Formulating was not significantly different from the corresponding OECD average.

PISA 2012 students in Ireland achieved an overall mean mathematics score (502) that was not significantly different from that of the UK as a whole (494). Like Ireland, students in the United Kingdom had a mean score on Space & Shape that was significantly below the corresponding OECD average. Students in Northern Ireland had an overall mathematics mean score (487) that was significantly below the mean score for Ireland and the OECD average. Students in Northern Ireland achieved a mean score on Space & Shape (463) that was below the corresponding OECD average, and a mean score on Data & Change that was not significantly different.

Figure 4 provides an example of a PISA Space & Shape item, where students are required to apply the Pythagorean theorem in a real geometric context. Students in Ireland achieved a mean percent correct score of 48%, compared with an OECD average of 50%. Given that the Pythagorean theorem features strongly on both the pre-2010 and Project Math syllabi, one would have expected students in Ireland to have done better.


Sailing Ships – Question 2

Approximately what is the length of the rope for the kite sail, in order to pull the ship at an angle of 45° and be at a vertical height of 150 m, as shown in the diagram opposite?

A - 173 m

B - 212 m

C - 285 m

D - 300 m

Figure 5: Sample PISA 2012 Mathematics Item

CONCLUSION

International studies of mathematics achievement can provide useful information about overall performance, as well as performance on mathematics content areas and processes. Data for Irish students from TIMSS 2011 (Fourth grade) and PISA 2012 (15-year olds) will soon be augmented with data from TIMSS 2015 (Fourth and Eighth grades), and from PISA 2015, where the mathematics test will be offered on computer only for the first time.

While Ireland performed above the OECD average on PISA paper-based mathematics for the first time in 2012, performance among students in Fourth grade on TIMSS 2011 was weaker, with students in Ireland lagging well behind a cluster of Asian countries, and several European countries, including Northern Ireland, Finland, England, the Netherlands, and Denmark.

Students in Ireland who participated in TIMSS 2011 mathematics showed a relative weakness on Geometric Shapes & Measures, and, to a lesser extent, on Data Display. Performance was also weak on the Reasoning process subscale. In PISA 2011, students in Ireland performed well on three of the four content areas assessed. The exception was Space & Shape, which covers spatial reasoning as well as more general mathematical problem solving.

Although the implementation of Project Maths, which began in all schools in September 2010[1], can be expected to bring about some improvements in all aspects of mathematics, it is unlikely that overall performance on PISA can improve without allocating more specific attention to Space & Shape, including a consideration of the cross-over between PISA Space

[1] Implementation of Project Maths began in 24 initial schools in September, 2010.

& Shape and the Project Maths syllabus. There may also be value in considering the extent to which the approaches to other aspects of mathematics in Project Maths (e.g., Algebra) are consistent with PISA Space & Shape. Finally, there may be value in providing short courses on spatial reasoning (e.g., Uttal *et al.*, 2013). A decline on PISA Data & Chance beteen 2003 and 2012 is also a matter of concern.

The relatively poor performance of students in Ireland on the Geometry & Measurement and Data Display content areas, and on the Reasoning process suggests that plans to revise the Primary School Mathematic curriculum (DES, 2011) should proceed without delay, and better bridges should be established between mathematics at the upper-end of primary schooling, and at the lower end of post-primary schooling (e.g., NCCA, n.d.). The recent publication of a *Shape and Space Manual* for primary schools by the Professional Development Support Service (2013) should also point to a broader range of activities for developing a sense of Space and Shape.

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Full Steam Ahead! Guiding Principles for the design of Interdisciplinary Approaches to the Development of Communication Skills and Enquiry Based Collaborative Learning in STEM and Arts Subjects

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Learning across the disciplines has become increasingly more conspicuous and desirable in contemporary higher education. Where universities' pedagogical and research approaches, and indeed structures, had evolved over time to be very clearly discipline driven, in the past 30-40 years, a shift has occurred which has resulted in a distinct move to also consider how the disciplines might (again) intersect and interact with each other.

As Weingart notes: 'Thus, disciplines … remain the primary organizational unit for the production and diffusion of knowledge. However, the process of differentiation … [has softened] the once rigid boundaries … to allow for the emergence of interdisciplinary fields…. traditional disciplines and inter-, multi-and transdisciplinary research fields will exist side by side' (Weingart 2010: 18). The necessity alone for language to describe this phenomenon suggests its prevalence. Klein's work is useful when examining this area as she attempts to evaluate this research field, noting the three phrases of multidisciplinary, interdisciplinary, and transdisciplinary in her work. With regards multidisciplinary exploration, Klein notes with particular reference to Stokols et al., that this involves 'juxtapositions of disciplinary approaches' but without modification of the disciplines (Klein 2008: 117). Interdisciplinary approaches are composed of stronger 'integrations and collaborations' involving the synthesis of two or more academic disciplines and their specific ways of thinking and methods, in pursuit of a common task.

Interdisciplinarity may feature when the subject is new, or neglected in traditional disciplines, such as, for example, global warming. Whereas transdisciplinarity, according to Klein referring to Rosenfield, occurs when 'different fields work together over extended periods to develop novel conceptual and methodological frameworks, with the potential to produce transcendent theoretical approaches' (Klein 2008: 117).

Our project involves exploring, what we are content to call, 'interdisciplinary' communication skills and collaborative learning across STEM disciplines. In order to examine this topic we completed a literature review and surveyed staff about their views on interdisciplinary communication and collaborative learning at undergraduate level. In addition, in late May 2014, we will hold a focus group on the topic with staff from our institutions and in Aug/Sept we will pilot a 6 week programme based on our research findings.

Though one of our intended project outcomes at the outset was to design a model for interdisciplinary approaches to communication skills, as a result of the literature review we have redefined our purposes and we instead, in the first instance, present guiding principles for the effective integration of interdisciplinary communication skills into existing and future programmes. In this paper we outline the first draft of these principles which recognise interdisciplinary collaboration as a pedagogical ‘trading zone’ and see the development of communications between the disciplines as a necessary response to the realities of world complexity, the dissolving of boundaries between subjects, the need to combat excessive specialisation, the drive for rounded graduates who possess scientific literacy, critical and creative thinking, and expanded expertise, vocabulary and tool sets, in addition to the ability to communicate with wider audiences. It is with reference particularly to the latter that we report on how our principles have been impacted by the very recent moves to integrate arts-based subjects with STEM disciplines -moving from STEM to STEAM. We suggest that this is an important transition of which we all need to be mindful.

Though a presentation of our comprehensive literature review is beyond the scope of this document, it is important to note that certain models and theoretical frameworks, in particular, influenced our work. These included: the US Boyer Commission of 1998; the Healey and Jenkins, and the Boyle and Bradley models of undergraduate research; the Aalborg model of project-oriented problem based learning (POPBL); the work on transfer most recently by Moore in the States; Wenger's work on communities of practice; and pedagogical constructivist methods particularly the move from absolute to contextual knowing as based on the research of Marcia Baxter Magolda. Our thinking was also impacted by the case studies on multi-, inter-and transdisciplinary higher education projects that appear in the literature.

Our key contribution, at this point, is to suggest some guiding principles which we hope will continue to evolve throughout our own work. We do not suggest that these ideas are absolutes, but rather that they appear to be held out in the literature and that they resonate with our own thinking and that of our colleagues who contributed to the survey associated with this project.

Our principles, thus, in their current iteration are as follows:

1: Interdisciplinary communication requires at least two people from different disciplines who each know their respective disciplines. For experts in different disciplines to work together effectively, they need to be able to communicate with each other. Where they are not, first and foremost, experts in their chosen field/discipline then there is little point in them trying to communicate with experts in other fields/disciplines. Therefore, at undergraduate level, the priority is to become as expert as possible in one's chosen discipline in the first instance. This does not mean becoming an information-repository for that discipline. Rather, expertise at this level involves emergent knowing, acting and thinking in a way that is recognizable to those who are identifiably initiated in the field. This expertise is associated with a familiarity with the culture, and ease of use of the language and conventions of the discipline. It is demonstrated in, amongst other behaviour, speaking, writing, arguing/case-making, and thinking in the discipline.

2. Key to undergraduate students developing interdisciplinary communication skills, is a recognition by students of the need for these skills and their value and importance. At discipline-specific undergraduate level, therefore, the main objectives may be to ensure that students grasp the essential nature of both intra-and interdisciplinary communication skills. Facilitating interdisciplinary learning means creating awareness in undergraduate programmes of disciplinary identity, and the variety that exists between different cultures and discourse communities.

3. The prevalence of communication modules in STEM programmes is indicative of widespread acceptance among faculty of the importance of communication skills. However, the conventional 'bolt-on' module approach is not the most effective way to either engender an appreciation of such skills or to begin to develop them. Theconcept of an 'interdisciplinary communication curriculum' in isolation seems fundamentally flawed at undergraduate level. The communication skills components need to be contextualized through their integration into the programme. The Aalborg POPBL model is a good example of such an approach.

4. As a shared entry point, enquiry should be at the core of interdisciplinary learning for STEM undergraduates. We see research informed pedagogies as being especially useful in this regard e.g. Enquiry, Problem and Project Based Learning.

5. Interdisciplinary learning must involve collaboration and peer learning as essential elements of all interdisciplinary undergraduate STEM programmes.

6. The ability to communicate within and across the disciplines is a necessary higher education curricular goal in an age of 'supercomplexity' (Barnett, 2000) and in a world where 'wicked' multi-faceted problems will need to be solved.

7. This work is not only the domain of writing and rhetoric experts but rather that this work needs to be of concern to all teachers and learners. In this regard, discipline experts - academics -need to work collaboratively across the disciplines and with learning support staff to develop interdisciplinary approaches. This will certainly include working with librarians, teaching and learning staff, writing and oral communication experts, research experts, etc.

8. An emphasis on scholarship is useful when designing interdisciplinary programmes where scholarship means facilitating learning for the student, as emergent scholar (Baxter Magolda, Healy and Jenkins) and where the teacher is engaged in scholarship across Boyer's four areas (1998)

9. All programmes of this nature should reflect learner centred approaches and should include the capacity for some learner driven outcomes.

10. The move from STEM to an integration of the Arts and Art and Design as part of interdisciplinary learning, what is emerging in the literature as STEAM, should be welcomed. We note these guiding principles here as a work in progress and our contribution to the important conversation that is happening in this area at present.

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Investigating Misconceptions in Mechanics Using MCQs

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Inquiry based learning places a strong emphasis on students questioning what they observe and analysing different possibilities. These skills are at the core of multiple choice questions (MCQs). The study reported here used a modified form of MCQ where students were encouraged to display the work they did in choosing their answers. The MCQ-tests examined the topic of Mechanics in Physics for Leaving Certificate. The concepts that caused greatest difficulty were identified. Misconceptions were also recognised and the "alternative thinking" that contributed to these misconceptions was explored. Many students had difficulty with aspects of motion and force in particular. Sixty questions were answered by 100 students in this study. The study took place in the academic year 2013-14. Teachers may find these results helpful in deciding what aspects to emphasize in teaching mechanics concepts.

INTRODUCTION

Multiple Choice Questions (MCQs) offer a valuable tool for learning. While their primary function is assessment of learning, they can be used to enhance learning. One of the advantages of multiple choice questions is that they are objective, so variations in marking due to subjective factors are eliminated (Jolliffe et al, 2001). MCQs are efficient because questions take less time to complete and less time to correct, compared to other forms of test (Simes et al 1997). Obviously, the more carefully crafted the question, the greater is the potential for learning. Questions which simply test memory of facts are quick to produce, and quick to answer but only serve a limited purpose. They only test the base level of Bloom's taxonomy of educational objectives…..Recall of facts. However, well designed MCQs have the capacity to test higher order learning like, comprehension, application, analysis, synthesis and evaluation. Through doing so, students are forced to think more deeply and hopefully reach a fuller understanding.

One of the most crucial things to do to probe student understanding is to choose really good *distracter*s that present the student with plausible answers that are not correct. This may deflect their attention from the correct answer and force higher order thinking to select the answer they believe to be correct. In the event that one of the distracter answers is chosen, it can reveal misconceptions that the student has, or uncertainties. Thus for effective learning to take place, the incorrect answers need to be teased out between student and teacher so that true understanding occurs.

In the early 1980s Hestenes and Halloun developed an instrument called the Mechanics Diagnostic Test (MDT) that measured the discrepancy between the students' common sense beliefs and their belief in the Newtonian force concept as taught in lectures. In 1992, an improved version of the MDT was published as the Force Concept Inventory (Hestenes et al, 1992). The Force Concept Inventory (FCI) is a test measuring mastery of concepts commonly taught in a first term of physics at University. The FCI could be used by any physics instructor to evaluate their own students. Another mechanics tests is the FMCE or Force Motion Concept Evaluation (Thornton & Sokoloff, 1998) which is an instrument similar to the FCI that looks at fewer concepts and makes heavy use of graphical and pictorial representations. The FCI and the FMCE are the two most commonly used physics concept tests in use today. Unlike most multiple choice tests, the FCI distracters come from common-sense student responses to open-ended versions of the questions used on previous occasions.

The research reported here was based on an attempt to apply the broad principles of the FCI and the FMCE to school physics classes in Ireland. Completely new questions were constructed tailored to the Irish Physics curriculum at Leaving Certificate level. The research was conducted in senior cycle classrooms in Ireland in the academic year 2013-2014. Nine teachers facilitated one or more tests with their students during normal teaching periods as part of assessment for learning consistent with the programme of study the students were undertaking. Some classes had as few as seven students and others had as many as twenty students. In some cases the students were in 5th Year and in other cases they were in 6th Year. The gender of the students was not identified as this was not under investigation. The nine teachers who participated were the ones who volunteered to do so out of a random sample of twenty who were invited to participate.

RESEARCH DESIGN

The topic of mechanics on the Leaving Certificate Physics higher level course was chosen for this investigation. The topic was subdivided into six units based on the subdivisions commonly recognised by most teachers. The six units were:

- Velocity and Acceleration
- Force, Mass, Momentum
- Pressure, Gravity, Moments
- Work, Energy, Power
- Circular Motion
- Simple Harmonic Motion

Questions were constructed using the Multiple Choice Question MCQ format where four or five possible answers were offered. Only one answer was correct, and the other answers were designed to be as plausible as possible and are referred to as distracters. The art of providing good distracters is an important skill in writing good MCQs (McKenna & Bull, 1999).The option to use two-tier MCQ was considered but since the Irish curriculum makes very infrequent use of MCQs it was felt that many students might be over-awed by the complexity of two-tier questions. The MCQ tests were designed to help both student and teacher to identify student problem areas so they could be re-taught to correct any misconceptions or areas of difficulty and develop a deeper understanding of a topic (Mann & Treagust 1998; Odom, & Barrow 1995).

The questions themselves were designed so as to appeal to different learning styles and to test different skills. A bank of questions was assembled involving a variety of styles including; some visual, some mathematical, some verbal, as well as those which required students to interpret graphs, or to solve problems. In order to achieve a degree of consistency and uniformity for the students and the teachers who would use these MCQ tests, each test had the following characteristics:

- Each test was contained on the two sides of a single A4 page
- There were ten questions on each test (five on each side)
- Each batch of ten questions had a variety of styles (verbal, visual, mathematical)

- Questions were graded so that questions one and two were easy and questions four and five were challenging (Similarly, questions six and seven were easy and questions nine and ten were challenging)
- Teachers could choose to set five questions or ten questions for their students to do at a time.
- Teachers could choose whether to allow five, ten or fifteen minutes depending on circumstance.
- As much space as possible was allowed on the page for students to write.
- Teachers were asked to encourage their students to display all relevant work (with the incentive that if the answer were incorrect, that the work might merit some attempt mark)
- In the event of an incorrect answer, the students' written work could be analysed to see the type of thinking that led the student to offer the answer they chose.

The content validity of the MCQ tests was established in three ways. First, early versions of the tests were critiqued by physics teachers and by graduate students. Second, the MCQ tests were taken by graduate students to verify agreement on correct answers. Third, the tests were read by a Science Teacher without a specialist Physics background to ascertain if the language of the questions and the multiple choice responses was understandable.

It is difficult to give the same MCQ tests to the same students twice after a meaningful time interval. Accordingly the reliability of the tests was established in the following two ways. First, the results of two class groups who completed the MCQ tests were compared to the results that the same students obtained on a conventional written exam on the same material. The same students did well both times and for the most part the same students who scored poorly in the MCQ also scored poorly in the conventional written exam. Second, the results of the various MCQ tests across several different class groups (taught by different teachers) showed similar patterns of answer profiles.

Upon completion of the tests, the teacher was asked to photocopy the student work, correct and return the originals and forward the copies to the researcher for analysis. Codes were assigned to each test received to facilitate *cross-analysis*. The copies of the tests were then corrected and the chosen answers; A, B, C, D and E entered in a spreadsheet. Numerical data was gathered on the sixty questions that were answered by one hundred students. This collated data on how many students chose the correct answer to each question and how many chose each other "incorrect answer" was analysed. Questions where significant numbers of students chose a particular incorrect answer were examined. In some of these cases possible interpretations are offered for the choice of answer or for the popularity of a particular answer.

FINDINGS

The responses from 100 students were analysed and the response levels for the various questions are therefore presented as percentages. In many cases, a high percentage of students chose the correct answer. However quite a large number of questions, approximately one third of the sixty questions revealed some interesting insights into where students had difficulty. In some cases an incorrect answer may indicate a simple lack of knowledge. In some cases there is a certain evidence of *misconception* and certainly examples of *alternative thinking* arise in many of the student responses. Some of the most noteworthy findings are outlined below. In some of the more difficult questions, students didn't choose any answer and so the percentages in these cases may seem not to tally. Percentages were calculated based on the number of students who sat the tests not on the number who answered any particular question.

Motion

When a ball is thrown vertically and returns to its starting point, which of the following is true?

A. Its velocity throughout is constant
B. Its acceleration was zero at the highest point
C. The time going up exceeded the time falling down
D. Its displacement is zero

The correct answer D was chosen by 52% of students. It is interesting to note however that 44% chose option B.

A car, starting from rest with constant acceleration, travels 64 m in 4 seconds. What is the magnitude of the acceleration?

A. 2 ms^{-2}
B. 4 ms^{-2}
C. 8 ms^{-2}
D. 16 ms^{-2}

The correct answer C was chosen by 51% of students but 45% chose D. They would appear to have concluded that division of the two given numbers was the best option.

A body starts from rest with a uniform acceleration, a. The time t taken for it to undergo a displacement s is given by

A. $t^2 = 2s/a$
B. $t^2 = 2a/s$
C. $t^2 = a/2s$
D. $t^2 = s/2a$

The correct answer A was chosen by 47% of students but 37% chose B. Perhaps some of those who chose B were familiar with $v^2 = u^2 + 2as$ and thought the 2a/s sounded right.

Momentum

When a cannon ball is fired and the cannon recoils which of the following is true?

A. the cannon's momentum is greater than the canon ball's momentum
B. the cannon's momentum is equal to the canon ball's momentum
C. the cannon's momentum is less than the canon ball's momentum
D. the sum of the two momentum values is zero

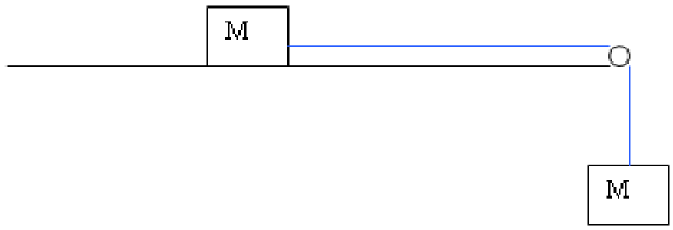
The correct answer D was chosen by 34% but 46% chose B. Some of the high number who chose B may have overlooked the vector nature of momentum.

Two bodies, each of mass ,m, are travelling in opposite directions with speeds of 4 ms^{-1} and 6 ms^{-1}, respectively, when they collide. After the collision they move together as one body with speed v. The value of v in ms^{-1} is

A. 10
B. 5
C. 2
D. 1

The correct answer D was chosen by 12% of students. The fact that 50% chose C may indicate difficulties with the use of mathematics in problem solving in Physics

Force
If the contact between the table and the box is smooth and if the pulley is smooth, and the inelastic string taut, and the masses equal, the acceleration of the hanging mass will be



A 2g
B g
C g/2
D 0

where g denotes the acceleration due to gravity

The correct answer C was chosen by 19% of students but 49% chose B

Gravity
The gravitational force between two objects in outer space is 5400 N.
How large would the force be if the two objects were three times as far apart?

A. 16200 N
B. 1800 N
C. 600 N
D. 200 N

The correct Answer C was chosen by 28% of students but 59% chose B.

Work

When a person holding a box applies a force of 40 N vertically upwards so as to keep the box stationary at a height of 2 m above the ground, the work done by the person is

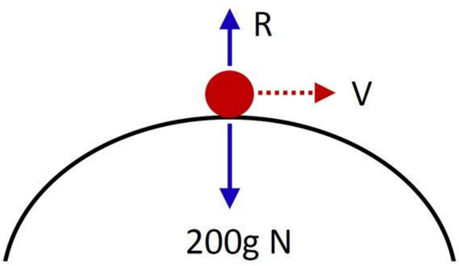
A. 80 J
B. 40 J
C. 20 J
D. 10 J
E. 0 J

The correct answer E was chosen by 26% of students but 35% of students chose A. This might indicate that some students missed the point that while the object is stationary, the displacement is zero and the resultant work is zero.

Circular Motion

A bridge is in the shape of an arc of a circle of radius 80 m. The greatest speed that a ball of mass 200 kg can travel over the highest point of the bridge without losing contact with the road is

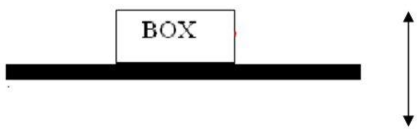
A. 32 ms^{-1}
B. 28 ms^{-1}
C. 24 ms^{-1}
D. 20 ms^{-1}
E. 16 ms^{-1}



The correct Answer B was chosen by 43% of students but 23% chose C

Simple Harmonic Motion

SHM1: A horizontal platform is oscillating in a vertical plane with simple harmonic motion of amplitude 0.05 m. The greatest number of oscillations per second so that an object at rest on the platform remains in contact with the platform at all times is



A. 7π
2π
B. $\frac{7}{\pi}$
C. $\frac{\pi}{2}$
D. $\frac{\pi}{7}$

The correct Answer C was chosen by only 15% of students but 18% chose B , 23% D and 24% E

SHM2: It is assumed that the depth of water in a harbour rises and falls with simple harmonic motion. On a certain day the low tide has a depth of 9 m at 1220 and the following high tide had a depth of 13 m at a time of 1820. Which of the following is true:

A. amplitude is 4 m and period is 12 hours
B. amplitude is 2 m and period is 6 hours
C. amplitude is 4 m and period is 6 hours
D. amplitude is 2 m and period is 12 hours

The correct Answer D was chosen by 23% of students but
21% opted for A, 18% for B and 19% for C

DISCUSSION

In the case of motion, many students struggle to accept that a body could have a non-zero value for acceleration when the body has a zero value for velocity. Teachers might need to emphasize that a ball thrown vertically is continually subject to the acceleration due to gravity until it returns to the hand that threw it. In the case of momentum, where a collision occurs between two bodies that approached each other, one of the initial velocities needs a negative sign, and many students didn't seem to consider this necessary.

In the problem where forces move a pair of bodies joined by a string, the two bodies form *a system* which then has properties different from the individual bodies. So the acceleration of the system needs to be considered, not just the absence of friction between one body and the table. In the case of gravitational attraction between two bodies it would seem that many students failed to appreciate the significance of an *inverse square* relationship between the quantities of force and distance.

In the question on Circular Motion where a body might lose contact with the road as if it travelled too quickly over a bridge, the concept of *reaction forces* seemed to present a difficulty for students and in particular the idea that the reaction equals zero at the instant that contact is broken.

The question on Simple Harmonic Motion (SHM1) where a platform went up and down with increasing frequency until a block placed on it first lost contact with the platform, required a lot of problem solving. The fact that a very small percentage got it right is testament to the challenge it offered. The fact that three of the distracters (incorrect answers) each accumulated responses of approx 20% may suggest that many students resorted to a guess and that there was no particular misconception in this case.

The second question on Simple Harmonic Motion (SHM2) the tidal problem, highlights that many students think that the amplitude is twice the true value and think the period is half its true value.

CONCLUSION

The findings in this investigation suggest that multiple choice questions can be effective in identifying where students encounter difficulty in understanding certain concepts in Mechanics. The findings give some interesting insights into the type of alternative thinking that was brought to bear by some students in answering the questions. The numerical analysis of the data gives an indication of whether the particular misconception is rare or common.

Teachers might feel that certain issues are worth an increased emphasis in their teaching. Researchers might be motivated to explore the reasons behind these misconceptions.

ACKNOWLEDGEMENTS

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APPENDIX

<u>MCQ-test: Simple Harmonic Motion</u>

Instructions: Outline on this page all relevant work leading to your answer. In the event of a wrong answer, your work may merit partial credit.

1 When a particle is travelling with simple harmonic motion its
A. displacement is proportional to its velocity
B. velocity is proportional to its acceleration
C. acceleration is proportional to its displacement
D. displacement is proportional to its speed
E. speed is proportional to its acceleration

2. With regard to the period of a simple harmonic motion which of the following statements is correct?
A. The period is the time for one complete oscillation.
B. The period is the interval between the times when the velocity is zero.
C. The period is the interval between the times when the acceleration is zero,
D. The period is the time taken to travel a distance equal to twice the amplitude.
E. The period is equal to the time taken to travel from one extreme position to another.

3. A mass oscillates up and down at the end of a vertical spring.
If the period of the motion is two seconds, the frequency is

A four cycles per second

B two cycles per second.

C one cycle per second.

D half of a cycle per second

4. The period of a simple pendulum is

A. proportional to its length

B. proportional to its length squared

C. proportional to the square root of its length

D. inversely proportional to the square root of its length

E. inversely proportional to its length squared.

5. A horizontal platform is oscillating in a vertical plane with simple harmonic motion of amplitude 0.05 m. The greatest number of oscillations per second so that an object at rest on the platform remains in contact with the platform at all times is

A 7π B 2π C $\frac{7}{\pi}$ D $\frac{\pi}{2}$ E $\frac{\pi}{7}$

<u>Assessment: Simple Harmonic Motion</u>

Instructions: Outline on this page all relevant work leading to your answer. In the event of a wrong answer, your work may merit partial credit.

6. For a particle travelling with simple harmonic motion about a fixed point ***0,*** which of the following statements is correct?

A. The acceleration is away from 0 when the velocity is away 0.
B. The acceleration increases as the velocity increases,
C. The velocity increases as the displacement increases.
D. The acceleration is a maximum when the velocity is zero.

7. A simple pendulum has a period of 1 s. The length of the string is approximately

A. 1 m   B. 2 m   C. 4 m   D. $\frac{1}{2}$ m   E. $\frac{1}{4}$ m

8. A particle is travelling with simple harmonic motion such that its acceleration, in metres per second squared, is equal to four times its displacement, in metres. The period of the motion, in seconds, is

A 4   B $\frac{\pi}{2}$ C π D 2π E 4π

9. It is assumed that the depth of water in a harbour rises and falls with simple harmonic motion.

On a certain day the low tide has a depth of 9 m at 1220 and the following high tide had a depth of 13 m at a time of 1820. Which of the following is true:

A amplitude is 4 m and period is 12 hours

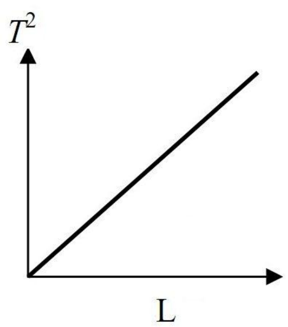
B amplitude is 2 m and period is 6 hours

C amplitude is 4 m and period is 6 hours

D amplitude is 2 m and period is 12 hours

10. A simple pendulum is used in an experiment to determine the value of the acceleration due to gravity g . A graph is plotted of period squared (T^2) against Length (L) as shown. If m is the slope of the graph then g is given by

A $\frac{2\pi}{m}$ B $\frac{m}{2\pi}$ C $\frac{m}{4\pi^2}$ D $\frac{4\pi^2}{m}$ E $4m\pi^2$



Primary Science and Creativity: Strange Bedfellows?

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Subjects like visual arts, drama and technology are by their very nature perceived as creative whereas science is not. This is observed in a simple comparison for words starting with 'creat-' in the visual arts and science curricula in the Irish Primary Curriculum. There are more than 100 instances in visual arts but just 16 in science. In this practice-focussed paper, a case will be made for the importance of creating space and time for creativity in the primary science classroom. The benefits of considering creativity in science will be shared, including supporting the development of science skills. Fortunately, the primary science curriculum naturally lends itself to creativity through its focus on investigations and problem-solving. Furthermore, inquiry-based science education is rich with opportunity for creativity. Other creative opportunities include using integrated approaches which can be employed to help children better understand science as well as develop scientific attitudes and skills. As well as sharing examples of such inquiry and integrated approaches, various aspects of pedagogy will also be considered through a creative lens.

INTRODUCTION

What is creativity in school (science)?

Creativity can be conceptualized in three ways; one is that it belongs to a particular sector for example the Arts; another is that is only evident in very rare people such as Albert Einstein; the third and the one that defines creativity in schools, is the ability for creativity in all sectors and by all people. This is democratic creativity. (NACCEE 1999) In an interview with Sir Ken Robinson, he stated that one misconception people have about creativity is that '*is that it's about special people—that only a few people are really creative'*. He adds that *'Everybody has tremendous creative capacities. A policy for creativity in education needs to be about everybody, not just a few*' (Azzam 2009).

Creativity is defined by four main factors: using imagination, pursuing with purpose, being original and judging value. On first glance, there may seem to be little space for being original in the primary classroom but this can be seen as a child thinking about things in different or unexpected ways, making connections between new ideas or experiences and old ones or finding novel solutions to problems which are new to them. Creativity requires a balance between generative thinking, the process of generating and exploring new ideas and analytical thinking, examining ideas and identifying strengths and weaknesses.

'*Being Creative*' is one of the six key skills of the new Junior Cycle Curriculum in Ireland (NCCA 2013). This development is welcome one. This key skills framework largely mirrors the focus on thinking skills and personal capabilities in the revised Northern Ireland curriculum (CCEA 2007a), where 'Being Creative' is also identified as one of the key skills and capabilities. By being creative '*Children should be able to use creative approaches to be imaginative and inventive, to explore possibilities and take risks in their learning'*. Furthermore the development of these skills and capabilities are at the heart of the Northern

Ireland curriculum from foundation stage right through to key stage 4, the full range of formal education.

More interesting in the Northern Ireland Curriculum is that in the primary curriculum area ‘The world around us – science and technology’, there is explicit guidance around being creative through curiosity, exploration, flexibility and resilience (CCEA 2007b). Here children are expected to be creative in science. This suggests a positive shift in the relationship between science and creativity. However, doing a simple comparison of words starting with ‘creat-’ in both the Science (DES/NCCA 1999a) and Visual Arts (DES/NCCA 1999b) primary curricula in Ireland reveals that while there are over 100 instance in visual arts, there are only 16 in science. These are shown in Table 1.

Table 4: The instances of ‘creat-’ words in the Science and Visual Arts Curricula

	Creativity	Creative(ly)	Create(s)(d)	Creation	Creating	Creature(s)
Science	0	4*	7	3	2	0
Visual Arts	4	11	60	1	24	5

BACKGROUND

Benefits of considering creativity in primary science

The importance of creativity in current education discourse is largely to do with children and young adults having the necessary skills and capabilities to face the uncertain and challenging future which lies before them. Natural resources are under threat and diminishing in a time of population growth. Access to clean water, food, education and health care will become ever increasing difficulties across the globe. This is coupled with the global concerns around climate change and energy resources. Sir Ken Robinson states that ‘*we're going to need every ounce of ingenuity, imagination, and creativity to confront these problems’* (Azzam 2007). Moreover, technology is developing at an unconceivable rate and the future possibilities and directions are vast. Additionally, employers are calling for innovative and critical thinkers to compete in a global market. Therefore, teaching for creativity is essential in education. This needs to start from the early years and continue right through to further and higher level education.

Of course, the role of STEM subjects in tackling these problems is crucial and creativity therefore needs to be central to these subjects. The primary science curriculum states that ‘*Investigations and problem-solving tasks nurture the inventive and creative capacities of children*’ (DES/NCCA 1999a p. 6) Furthermore, one of the core aims is to ‘*foster the child’s natural curiosity, so encouraging independent enquiry and creative action’* (p. 11). This suggests a strong link between creativity and investigations and enquiry. Investigations and enquiry demand that children develop and use scientific skills. The science curriculum (DES/NCCA 1999a) states that science skills will be developed as work is completed on the strands and strand units of the curriculum. This is important and we would strongly advocate for working scientifically taking the central stage in primary science. As well as fostering creativity, through working scientifically children also develop important scientific attitudes such as curiosity and respect for evidence. There are seven key skill areas which are developed through the primary curriculum. Each of these encourages creativity and allows for children to be creative. As part of the new Junior Cycle Curriculum (NCCA 2013), learning outcomes for ‘Being Creative’ have been devised. Table 2 shows the working scientifically skills developed across all stages of the primary science curriculum and how these link to being creative using these 'Being Creative' learning outcomes as a framework.

Table 5: Working scientifically skills developed across all stages of the primary curriculum mapped to being creative

Working scientifically	**Being creative learning outcomes (NCCA 2013)**
Questioning	Imagine different scenarios
Observing	Seek out different viewpoints and perspectives
Predicting	Predict different outcomes
Investigating and experimenting	Think through a problem step-by-step, test out ideas, try out different approaches when working on a task, take risks and learn from mistakes and failures
Estimating and measuring	Repeat the whole exercise in necessary
Analysing	Evaluate different ideas, evaluate what works best
Recording and communicating	Express my ideas through movement, writing, music, art, story-telling and drama

While the 'Being Creative' framework offers some scope for thinking about creativity in science, it neglects other areas such as working with others, communication and using information. These are all important aspects of creativity. Fortunately, these are also recognized as other key skills within the new Junior Cycle Curriculum (NCCA 2013). Sir Ken Robinson recognized the central importance of collaboration in creativity stating '*The great scientific breakthroughs have almost always come through some form of fierce collaboration among people with common interests but with very different ways of thinking'*. (Azzam 2009) Furthermore, he offers that collaboration, diversity, the exchange of ideas, and building on other people's achievements are at the heart of the creative process. Therefore, children need to have opportunities to share ideas, work collaboratively together, build on existing ideas and to follow their own ideas in science to allow for creativity to flourish. Luckily these are easily achieved in the primary science classroom, particularly one which advocates and values experiential and inquiry based approaches to science education.

CREATIVE APPROACHES IN SCIENCE EDUCATION

Inquiry based science education (IBSE)

IBSE is being advocated in both Europe and beyond (Rocard et al. 2007, Osborne and Dillon 2008, National Research Council 2012) According to Rocard et al. (2007) inquiry based approaches proved their efficacy in science learning at primary level with increasing both children's interest and teachers' willingness to teach sciences. In this report, it was stated IBSE emphasizes curiosity and observations followed by problem-solving and experimentation. Also, inquiry-based methods provide children with opportunities to develop a large range of complementary skills such as working in groups, written and verbal expression, experience of open-ended problems solving and other cross-disciplinary abilities. An inquiry based approach has the potential for promoting creativity, however such experiences need to be carefully planned to ensure that these are child led rather than teacher led and allow for real collaboration and exploration. They also need to be purposeful so that children can judge and evaluate the outcome, solution or product.

Cross-disciplinary approaches

There is also real potential for creativity when science teaching and learning is integrated with other subjects. As already highlighted the Arts can be seen as the home for creativity and this is with good reason. However, visual arts, drama and music can be integrated effectively with science to encourage creativity and develop knowledge understanding and skills. For example, stories provide a natural hook for children and from here they can explore a myriad of science concepts using drama techniques such as freeze-frame and conscience alley. Kelly (2012) described the use of the popular Disney story 'Finding Nemo' and drama to develop science ideas around food chains and habitats. From here the discussion can move to controversial issues such as over-fishing and whaling.

Integrating science with visual arts has particular scope when considering living things. Painters the world over have been inspired by the natural world. By doing pencil drawings, children are encouraged to develop their observation skills, noticing details such as lines, textures and colour. This is particularly effective when considering one object e.g. a leaf, a snail or a cut orange. Children will begin notice less obvious features. Such observations have the potential to lead to questions which may then open the path to a child-led investigation. This provides a snap-shot of the potential for creative approaches in science. Teaching science outside the classroom, considering the science of health and well-being and the science of sustainability and other controversial issues all offer scope for creativity teaching and teaching for creativity in primary science. These are discussed in the forthcoming publication by Cutting and Kelly (2014).

Pedagogy for creativity

While such approaches may seem inviting, teachers' concerns around the demands of planning and assessment may be a natural barrier. However, luckily in Ireland teachers are free to choose how and when they assess their children. Equally approaches that allow for children to self-and peer- assess are encouraged. The classroom assessment methods promoted by the NCCA (2007) include:

- Self-assessment
- Conferencing
- Portfolio assessment
- Concept mapping
- Questioning
- Teacher observation

The inquiry-based approaches advocated in this paper along with collaborative learning offer scope for teacher observation and conferencing. Equally when children are engaged in inquiry and other creative endeavors teachers can question children for both formative and summative purposes. Through concept-mapping children can make sense of their own ideas. This is where the balance between generative and analytical thinking, central to creativity, is important. Children can use concept maps to generate ideas, making connections between ideas and experiences, however, analytical thinking is needed to ensure these ideas make sense and are purposeful to the task at hand.

Every lesson and scheme of work should be carefully planned and this is no different when considering creativity. Creativity won't just happen in the classroom without the teacher planning experiences and activities which have the correct balance of teacher input and independence and choice for the children. Equally the resources available and the timing need to be considered. Again, these issues and others are further discussed in Cutting and Kelly (2014).

CONCLUSION

In this period of welcome curriculum reform and consultation, it is essential that creativity is seen as a skill which is encouraged and developed across all areas of the curriculum and at all levels. The NCCA will shortly be inviting contributions for their consultation *Primary Curriculum: New Pathways for Teachers and Children* (NCCA 2014) and it is hoped that this paper has provided some food for thought and made a case for creativity in primary science. It is however acknowledged that initial teacher education needs to respond to such changes. Equally continuing professional development courses are needed to develop teachers' confidence in such approaches and methods. This has been an issue when implementing inquiry-based approaches in Ireland and more widely. (Dunne 2013)

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Sociocultural Lessons for Reform-Based Mathematics: Tracing Pedagogical Shifts in a Transition Year Classroom

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INTRODUCTION AND CONTEXT

The Transition Year (TY) programme which was introduced in 1974 is unique to second level schools in Ireland. As a senior cycle option, it affords students the opportunity to experience different academic subjects, develop new interests, become creatively innovative and engage in vocational preparation (Department of Education and Science, 1994). Its rationale appears to have been based on a desire to move away from a completely exam-orientated system to allow students to be more receptive to new ideas and to develop deeper independence and a higher capacity for conceptual understanding. The Guidelines for TY (ibid.) recommend a balance between academic subjects and a sampling of subjects (e.g. law, media studies, etc.) not generally provided by the school. The core of the programme offers mainly six subject areas: academic subjects, cultural studies, sports, computer studies, work related learning and civic/social studies. All schools offer academic subjects – generally Irish, English, mathematics and a modern European language. TY mathematics offers the opportunity for a more open approach, with a range of methods of presentation and exploration of topic to help stimulate and maintain students' interest. The guidelines for TY advise that with mathematics education:

"The approach taken ... is as important as the content itself. It should seek to stimulate the interest and enthusiasm of the pupils in identifying problems through practical activities and investigating appropriate ways of solving them. In this way, study can be brought into the realm of everyday life so that the process appears to be more pupil-directed than teacher-directed" (ibid, p.10).

Such an approach is also congruent with the aims of Project Maths which envisages ongoing change to students' learning and assessment in mathematics with a much greater emphasis on conceptual understanding and on the application of learning to other contexts and to the real world. TY mathematics and Project Maths both encourage teachers to reject traditional teaching in favour of more progressive methods which "enable students to have a valid and worthwhile learning experience with emphasis given to developing studying skills and self-directed learning" (ibid, p.3). In teaching TY modules, the guidelines suggest the use of negotiated learning, activity-based learning, group work, project work, visiting speakers and day trips. For mathematics teachers these 'progressive' methods imply, for example: facilitating student-led investigations; supporting students' presentations; using spreadsheets, computer programmes and the internet; engaging with print and mass media; and interacting with people, workplaces and institutions involved with mathematical expertise. The authors of this paper have followed these methods closely while implementing a teaching and learning plan faithful to sociocultural principles. The plan provides for: a variety of activity (such as designing an apartment and recording the cost of living); different forms of action (such as measuring and presenting); and use of a range of tools (such as calculators and the internet). At its heart is questioning and enquiry with students becoming actively engaged in their own learning. The TY curriculum plan facilitates students' co-construction of knowledge, their formulation of new knowledge connections and their linking of mathematics to other subjects and to the real-world.

TY affords students space to mature free from exam-stress so that they may make more informed choices about further education and vocational preparation. It is established that TY students become more learning focussed (Smyth, Byrne and Hannan, 2004) and generally continue to third level which, in turn, enhances their life and employability prospects. In our view, the key pedagogical value of TY is its engagement with more novel ways of learning that enable students to become confident self-reliant individuals as they meet the challenges of Twenty-First Century society.

SOCIOCULTURAL LESSONS FOR MATHEMATICS LEARNING

Sociocultural theory proposes that students learn collaboratively with language playing a key role in the development of their higher mental processes (Vygotsky, 1962, 1978). Here we consider three of its specific conceptual lessons in relation to TY students' mathematics learning: classroom methodology; assessment; and identity change. In school classrooms, speech, writing, and visual forms of literacy as well as other social tools such as ICT, help mediate social interaction as students work together to develop shared meanings (Wenger, 1998). In keeping with TY aspirations, students are encouraged to "participate in learning strategies which are active and experiential and which help them to develop a range of transferable critical thinking and creative problem-solving skills" (DES, 1994, p.1). Formative assessment plays an important role in this process as it appraises, and evaluates students' performances and uses these profiles to shape and improve their competence (Gibbs, 1999). This complementary assessment process facilitates identity formation leading to a deeper sense of *self* development (Penuel and Wertsch, 1995). Students are challenged to become active learners, with the teacher no longer being the knowledge-provider but rather a creator of classroom possibilities that stimulate personal and critical forms of mathematical learning (Conway and Artiles, 2005; Van Huizen *et al*, 2005). Let us now consider the first sociocultural lesson for mathematics.

Classroom Methodology

We sought to develop a mathematics teaching and learning plan inspired by sociocultual learning theory. This plan provided a framework for classroom activities. At the start of class it was important to introduce the learning objective(s) of the activity, giving students a focus and a general approach to new subject knowledge. Thus, a conceptual idea is introduced for exploration – this may be a statement proposing an open investigation such as finding the dimensions of shapes with volume equal to 216 cubic centimetres. As students concentrate on this, their questions and real-world experiences become apparent. By listening to their contributions, the teacher becomes familiar with the students' prior knowledge upon which new understandings will be constructed. Further ideas and suggestions are elicited with such questions as: "What do you think?"; and "Why this?", etc. Sufficient 'wait time' for inner thinking is provided, while students' unique approaches to problem-solving are evaluated and praised. In this way, the teacher models the type of learning attitudes and actions which students are expected to engage with one another, as they work collaboratively. In effect, these 'hidden curriculum' insights present key 'learning to learn' lessons in the mathematics classroom.

Over time, the teacher encourages the growth and development of "a community of practice" (Lave and Wenger, 1991, p.98) in the classroom within which additional characteristics of sociocultural theory are recognisable. Such characteristics include: linking scientific and everyday knowledge; allowing students to put their own words and understandings on the ideas they explore; mediating students' actions by material and symbolic tools; scaffolding – by means of the zone of proximal development (ZPD, see later discussions) and peer groups supports; facilitating individual and collaborative interaction; and group problem-solving. Since "each learner presents a unique profile of abilities, accomplishments, characteristics and needs" (LaCelle-Peterson, 2000, p.39), each class period is different – a position upheld by sociocultural acknowledgement of the power of "situated learning" (Lave and Wenger, 1991, p.30). Within the social and cultural environment of the classroom, both teacher and students work collaboratively together until common knowledge ideally emerges (Gutiérrez *et al*, 1999). They take ownership of this knowledge and, with time and maturity, become more independent learners.

Assessment

Curriculum and assessment are integral to each another – one guiding objectives, the other seeking assurances that they are being achieved. In facilitating this iterative process, assessment should be a two-way flow, providing "…accurate information with regard to pupil strengths and weaknesses, and [being] formative, so as to facilitate improved pupil performance through effective programme planning and implementation" (Sullivan and Clarke, 1991, p.45). The TY Guidelines (1994, p.4) recommend that: "appropriate modes of assessment should be chosen to complement the variety of approaches used in implementing the programme". Reports, projects, student diary or log book, etc. are among the suggested assessment modes with freedom of type and use advocated. Student involvement is key in facilitating *their* ownership of learning.

The challenge for the teacher is to integrate methods of assessment which measure students' potential for growth by providing information on "those functions that have not yet matured but are in the process of maturation" (Vygotsky, 1978, p.86). Formative assessment provides feedback for teachers and students on the promotion of effective learning over the course of instruction. When teachers identify how students are progressing and where they have difficulty, they can then make instructional adjustments to promote learning using different approaches. According to an information leaflet produced by the NCCA, Assessment for Learning (AFL) is an appropriate means – being referred to "as formative assessment as its intention is to form, shape or guide the next steps in learning". Student-involvement in the process of assessment facilitates "greater self-awareness and an increased ability to manage and take responsibility for personal learning and performance" (DES, 1994, p.4). Some practices supporting AFL are: classroom questioning, peer and self-assessment and 'comment only' marking (see Black and Wiliam, 1998, 2003; Stiggins, 2002; NCCA, 2005).

Questioning seeks to improve the interactive feedback between students and teacher. By allowing more time for students to answer questions, they become more involved in classroom debates and discussions. Moreover, students are encouraged to explore the validity of their thoughts, to make assumptions, to find convincing arguments to support these assumptions or to find inconsistencies in the thinking of others. Such flexibility in their thinking is important so that they can understand different points of view, and be willing to change their beliefs when further knowledge comes to light. Answers are carefully attended to so that students receive meaningful responses that challenge and enable them to extend their knowledge. The procedure of answering of 'a question with a question' (particularly on the part of the teacher) gives credence also to the importance of problem-posing, as well as problem solving. During this interactive practice, teachers learn more about the thought processes of students, including gaps and misconceptions in their knowledge, and can witness the 'scaffolding' act advancing learning (Bruner, 2006). In 'comment-only' marking, correct work is acknowledged, weaknesses are mutually recognised and advice regarding improvement is forged. Here there is emphasis on learning rather than on performance. With peer- and self-assessment teachers encourage students by providing opportunities to appraise their own and others' work and to review and record their own progress. This gives them valuable insights into their: achievements; understanding of weaknesses in their knowledge; and plans for self-development. With such insights students are well placed to advance their learning and to become more active members of a community of practice.

Identity

Over time, changes in both teacher and pupils may be perceived. The teacher's role becomes imperceptibly modified from being (predominantly) a transmitter of knowledge to (gradually) a facilitator of a sociocultural learning climate that enables students to explore their own learning. This involves considerable personal change (see later discussions). In addition, teachers' professional practices develop to include capacity to: nurture collaborative inquiry; facilitate team work; follow students' thinking; scaffold students' knowledge; and assist students to scaffold each other's knowledge. Overall, classrooms transform gradually to "knowledge-creating communities with questioning and inquiry being central aspects of this process" (Sunderland, 2007, p.40).

In a sociocultural learning climate, students are no longer passive receivers of knowledge; rather they draw on their own prior understandings and actively co-construct new knowledge in more meaningful and collaborative ways (Wenger, 1998). Within a social setting, they look to one another for knowledge, to make decisions, connect mathematics to the real-world, discover information for themselves and establish new knowledge links. While working as creative and constructive problem solvers, their confidence grows and they become more independent learners. Gradually the teacher-student power relationship narrows, as students develop more positive attitudes towards mathematics learning and feel more encouraged to share curriculum choices. To illustrate, students in this study suggested that more student-designed PowerPoint presentations and exhibitions of their work in mathematics be facilitated. It was also recognised that such change would also help them to improve their ICT and public speaking skills. Such 'organic change', so-called because it is not 'forced' on the teacher and students, happens over time at a different 'pace and space'.

A NOTE ON RESEARCH METHODOLOGY

This paper emerges from a wider qualitative research study which took place over two consecutive school years from September 2008 to May 2010. It involved two separate TY classes in a co-educational voluntary secondary school. In the first year of the study there were twenty four students in the class (twelve girls and twelve boys), while in the subsequent year there were sixteen students (twelve girls and four boys). All students had completed Junior Certificate mathematics in the year previous to TY, with thirty six taking higher level and four ordinary level. The main author of this paper was the teacher in the classroom, who had taught many of the students in Junior Cycle and who sought change from traditional to reform teaching approaches. She was supported by advice and encouragement from the co-authors of this paper who acted as mentors offering careful empirical direction and informed conceptual focus. There were ongoing observations of the students by their teacher during their mathematics classes, which consisted of two periods of thirty five or forty minutes and one ‘double’ of eighty minutes each week. Traditional methods of drill and practice had been previously used to teach mathematics with a strong emphasis on the use of a textbook. Assessment had been in written form, with class tests at the end of a topic or at mid-term and formal end of year examinations in operation.

As the on-going emphasis was on interpreting learning in a social setting rather than testing a particular hypothesis, the research methods used were consistent with the interpretivist paradigm and associative qualitative approaches. These included: classroom observations; field notes; samples of students’ work; researcher diary; and focus group interviews. Observation was largely unstructured and although its general focus was clear, there was little clarity initially. Indeed clearer observations emerged over time alongside greater conceptual elucidations of events. Through spending time in the classroom, patterns emerged that greater evidenced theoretical categories. Conversations with students and amongst ourselves also helped to shed light on ongoing and eventual changes. Students were observed during class in relation to changes in behaviour, attitudes, responses, body language and application to tasks. All change was noted as near as possible to their actual occurrence in class. From the beginning of the study, key words, phrases and short quotes were written as accurately and as objectively as possible. Efforts were made to ensure that the note-taking did not interfere with the flow of the lesson or the pupils’ actions and reactions. Detailed notes were made later which documented the engagement of students with the knowledge substance, their interactions with each other and the measure of progress of both teacher and students in eliminating the conventional teaching methods of teacher-led exposition and individual student practice. Samples of students’ work too were gathered by the teacher to evidence the change (if any) of the students’ engagement with reform mathematics. Throughout the project the teacher kept a diary, which became more personal/professional in nature, compared to (arguably) the more objective professional focus of field notes. Here there was opportunity to subjectively reflect on the research, consider changes of direction, generate new ideas, comment on pitfalls, problems, etc.

Students’ and parents’ views about mathematics learning were also explored by means of semi-structured focus group conversations. Questions were of an open nature, providing a frame of reference for answers, but putting little control on participants to allow for a free flow of information. Students’ thoughts were sought on how they thought the teacher expected them to work in class, the best ways they had found to learn and understand mathematics, the renewed classroom arrangements, homework and methods of assessment they found most effective and their views on the mathematics curriculum and its improvement. Parents’ opinions were evoked on their own in-school mathematics learning, their expectations of and benefit to their children of TY mathematics, reform-teaching, homework and assessment.

During this study, data obtained by different research methods required specific and inter-related analyses. The qualitative data was continually and eventually categorised with recurring themes being identified that formed a basis for a multi-related coding system. As there was no set method of coding, what was involved was a mutual fitting between data and categories. Some data fitted into more than one category, other data did not fit neatly into any category, while other data created its own category. With the fieldwork and data collection ‘officially’ concluded, a continuous cycle of reading, interpreting and editing helped to develop the categories, elicit key findings, as well as possible recommendations and issues for further inquiry. The three main themes of sociocultural reform discussed in this paper - classroom methodology, assessment and identity shifts – were evidenced empirically. These are discussed below. Together they harmonise to engage and progress students’ interest in mathematics – important at a time when the teaching and learning of mathematics in Irish schools is perceived to be 'causing concern' (Engineers Ireland, 2010).

THE EMPIRICAL STUDY: TRACING SHIFTS IN TEACHING AND LEARNING

This section of the paper describes key pedagogical changes which occurred during the implementation of a mathematics teaching and learning plan that was informed by sociocultural learning principles (Vygotsky, 1962, 1978; Boaler, 1997; Moll, 1990). Aspects of the plan are now described together with related changes in classroom methodology and assessment and emergent student and teacher identities. The change process was not without challenges as traditional pedagogy conceded to a reform-based approach to mathematics that engaged, inter alia, more open problem-solving and group-based activities.

The teaching and learning plan for TY mathematics was not 'set', as it allowed for change owing to constant feedback from pupils, most recent teacher observations, etc. The plan provided for personalised forms of learning, placing the students' abilities, needs and interests at the centre of the educational encounter. There was "more emphasis [placed] on hearing students' voice and encouraging them to be partners in their own learning, rather than spectators" (NCCA, 2008, p.28). In this way, it was possible to engage students in intrinsic mathematical explorations that aim towards 'discovery learning' that is centred on meaningful mathematical knowledge. Students actively co-constructed the plan in a variety of ways: some topics were extended to several class periods when their explorations required more in-depth analysis; other topics were introduced in advance and their views sought on best ways to progress them; while in conversation with the teacher, students made recommendations on the retention, moderation or exclusion of content. The plan was deliberately non exam-driven; rather, it sought to develop concept formation and greater connections of knowledge to the real world. Thus, it was in keeping with the ethos of TY, Project Maths and reform-based teaching.

Material was presented in a variety of different *formats* including two and three-dimensional representations, photographs, handouts, drawings, games, computer applications and classroom visits. The wider society provided the framework for *contextualising* knowledge through the use of monetary currency, market products, newspapers, magazines, buildings, people, projects, etc. Such knowledge is more likely to make sense to young people who, in turn, use the tools and artefacts of culture to promote their conceptual development and express themselves more meaningfully (Solomon *et al*, 2006). These features contribute to the breadth and balance of the programme, facilitating students' coherence of similar knowledge in diverse situations (Gutiérrez and Rogoff, 2003). Meaning is derived from social interactions and the relations students form with others in the learning activity (Wenger, 1998). Sometimes these interactions are with the teacher or more knowledgeable peers, while other times with peers of similar but uneven knowledge repertoires. In this way, students learn to interpret meaning in keeping with the shared understandings of others and are enculturated into a community of practice of mathematics (Brown, 1997).

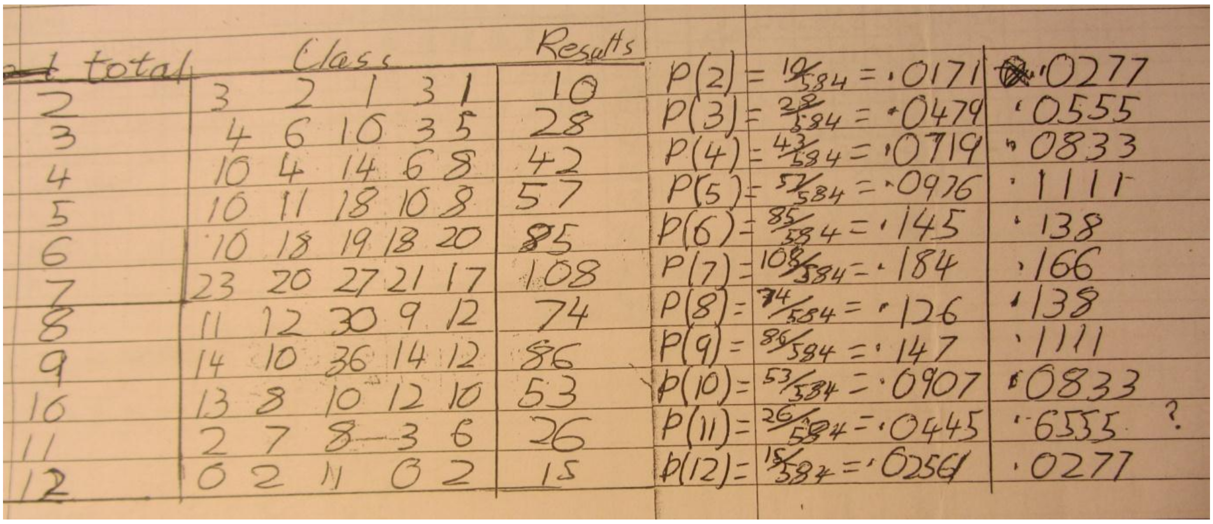
The teaching and learning plan included in this study provides for a variety of activity, ranging from the everyday (e.g. shopping and cooking) to those that are highly specialised (e.g. banking and architecture). One of the mathematical activities involved students designing the layout of a household vegetable garden. This novel project unearthed major gaps in their knowledge such as the names of some vegetables, their appearance, the optimal spacing for growing, tending, etc. To stimulate their thinking the teacher introduced the class to gardening books, magazines, packets of seeds and examples on the internet – classroom resources at odds with traditional classroom practice. Two students with experience of vegetable growing helped answer some of their peers' questions and guided access to further information. The classroom formed a forum for inquiry and exchange, with the project culminating in the cultivation of a garden in co-operation with the agricultural science teacher and her students. This brought home to us the idea that mathematics could be a living discipline for them. It seemed to suggest that the subject could be disassociated from its oft dispiriting image of being remote and lacking context – the latter all too frequently associated with traditional forms of methodology.

In further contributing to ethnomathematics (Gerdes, 1994: Radford, 1997), students were encouraged to bring relevant newspaper and magazine articles to class and to tell their peers briefly what they were about. Over time they became practised at this, presenting interesting items without invitation, thus connecting scientific with everyday concepts (e.g. Vygotsky, 1962). An article on obesity had information on body mass index, while another on sleep showed graphic age comparisons between peoples' sleep patterns. These indicated their growing awareness of mathematics in the world around them. It also gave students an opportunity to source material of interest to them and become providers of knowledge to the class. Conversations with students evidenced their deepening understanding as they connected mathematics to real life. One of the students, Sharon (pseudonyms used throughout), noted:

> "I have good memories of TY maths. I actually really enjoyed them and I liked them. I think I just really understood them really well. It hadn't happened before. It really clicked in TY and all the maths I had learned for Junior Cert. made sense. It had meaning."

Parents confirmed this too with such comments as "They [mathematics] had come alive for her." This contrasted hugely with their own experiences of school mathematics which they identified generally as "a lot of rigour and rules" and "rhyming things off." Learning sociocultural-based mathematics had meaning.

The plan also accommodated a variety of forms of action – sometimes physical with measuring, recording, sowing seed, etc., while at other times, verbal (e.g. presenting projects). More usually both physical and verbal actions occurred, such as during the course of tossing coins for a probability experiment, or finding volumes and surface areas of irregular shapes.



total	Class	Results		
2	3 2 1 3 1	10	P(2) = 10/584 = ·0171	·0277
3	4 6 10 3 5	28	P(3) = 28/584 = ·0479	·0555
4	10 4 14 6 8	42	P(4) = 43/584 = ·0719	·0833
5	10 11 18 10 8	57	P(5) = 57/584 = ·0976	·1111
6	10 18 19 18 20	85	P(6) = 85/584 = ·145	·138
7	23 20 27 21 17	108	P(7) = 108/584 = ·184	·166
8	11 12 30 9 12	74	P(8) = 74/584 = ·126	·138
9	14 10 36 14 12	86	P(9) = 86/584 = ·147	·1111
16	13 8 10 12 10	53	P(10) = 53/584 = ·0907	·0833
11	2 7 8 3 6	26	P(11) = 26/584 = ·0445	·6555 ?
12	0 2 11 0 2	15	P(12) = 15/584 = ·0256	·0277

Figure 1.1: Sample Space on Outcomes of Tossing Two Dice

During one of the investigations students completed a sample space on the expected results of totals on tossing two dice. Then they worked in groups replicating the event and recording the outcomes while later they combined the class results to probe how closely they matched with the expected results (Figure 1.1). Here classroom methodology allowed for discussion and physical interaction among students as they learned to align theory with reality and become active learners. It provided scope too for self-assessment as is shown by the question mark alongside the result 0.6555. This evidenced the student's realisation of its variance with the findings in general and of the failure of the numbers to add to 1. Such self-assessment is immediate, allowing the student to examine mitigating factors while the investigation is 'live' with guidance available from peers and/or teacher.

While being engaged in a variety of activity and forms of action students also learn to use tools, both semiotic (e.g. signs and symbols) and physical (e.g. calculators and protractors) which both aid investigations. The use of three-dimensional models, concrete materials and structures helped students apply their classroom information to the real world. A shoe box and cord representing the 'Spider and the Fly'[2] problem facilitated analysis of how the spider at one end of the cord might reach the fly at the other (Figure 1.2).

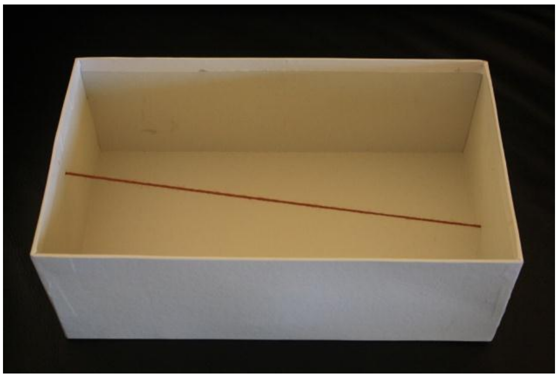


Figure 1.2: Representation of 'The Spider and the Fly' Problem

In the investigation the fly was 1m from the ceiling on the centre of a wall, while the spider was 1m from the ground on the opposite wall. Students envisaged a series of possible routes, committed related steps to paper, outlined and performed accompanying mathematical calculations. Here they learned how to: change perspective from three-dimensional to two-dimensional representation; have different approaches to a problem; and explore various solutions. The use of the shoe box eliminated much of the explanation required in the traditional classroom as students had a concrete representation of the investigation. Furthermore, it assisted in following students' thinking as various options were explored and evaluated. Such use of tools and materials renews the teacher's classroom methodology as he/she seeks to revisit the mathematical representation of enquiries.

Language as a mediational tool plays a major role in students' concept formation (Wertsch, 1985). They listen to explanations in everyday language, ask questions, argue their point of view, talk, think quietly to themselves, etc. Their own idiom and forms of oral expression intertwines with the more formal language of mathematics. 'Official' (often class and adult-based) forms of language can be more easily absorbed when spoken in conjunction with their own speech in the context of their lived experiences. Through language students are enabled "to internalise the world they experience in the living of their lives" (Hasan, 2002, p.113). On one occasion a student stated that she saw no use for the 'Tan of an angle' in trigonometry. A few days previously she had climbed Croagh Patrick with others and in conversation about it, she learned to relate the ease and difficulty of the climb with the incline of the ground (Solomon *et al*, 2006). "We made good progress at the start as the ground was not so steep but after a while we slowed down as it got very steep", was one of her observations. Together with the class, she utilised rough drawings of a cross-section of the mountain to relate various changes in steepness to the difficulty or ease of the climb. Making the connection between the incline of the mountain to the slope and Tan of its angles facilitated the introduction and understanding of formal mathematical language. Here the exploration of the student's personal knowledge and the forging of connections with scientific knowledge enabled her to make her own subjective meanings. This relates to the sociocultural principle that language is not just a medium for communicating ideas but also fundamental to the formation of ideas and concept development (e.g. Jaworski, 1999).

Students' voluntary attention and active participation are important requirements for the success of learning experiences provided for in the teaching and learning plan. Topics included are designed to encourage students' participation in learning and to prompt them to nominate and carry out their own investigations. Such freedom can help contextualise learning, lead to deeper understandings, and "offer pupils space to learn, mature and develop" (DES, 1994, p.2). One of their investigations involved getting the height of a tree in the school grounds by using a protractor and a single desk to find the angle of elevation of its top, and a tape to measure its full distance. On arriving at the tree, they found the grassed area uneven so they placed the small desk on the concrete path nearby. James, one of the students, objected saying "we will get a better angle nearer the tree, so, we should stay on the grass." Fionnuala, one of his classmates, explained to him that being adjacent to the tree did not matter as each time the table was at another distance, the angle would change to allow for it. She used her arm to point to the top of the tree and aligned it with her line of vision at different distances from the tree to show him. They placed the protractor on the desk holding it erect and tried to read the angle to the top of the tree. Claire suggested that it should be moved to the table's edge and another student might look from its centre to the top of the tree to read the angle – which measured as $58°$. They then measured the distance between the tree and the table, and the height of the table, while all participants recorded the information. Their active participation facilitated deeper understanding in an investigation 'outside' the classroom. It was also a new way for them to work together, and they successfully valued and assessed one another's contributions.

During investigations students brought their previous experiences, knowledge, beliefs and perhaps misconceptions to projects and then took responsibility for either learning or re-learning these. In the following example, they worked out possible ways of selecting a committee of two from two men and three women. Conal, a student, thought that the answer was six and he asked Gerry, another student, why it was ten. Gerry wrote A B C D E in his copy to represent the five people. Then he selected them in pairs AB AC AD AE BC BD BE CD CE DE and counted the ten selections. Conal realised that his mistake lay in thinking the committees had to be always a man and a woman, when at times it could be two men or two women. In co-constructing knowledge, students learned both to demonstrate and defend their methods and beliefs, thus contributing to their growing confidence.

By being actively involved in learning students were enabled to include latecomers and recent absentees by explaining current mathematical investigations, while they in turn asked questions and made proposals. As the newcomers became more competent they moved to full participation, indicating that learning is not simply the acquisition of knowledge but rather a process of social participation (Lave and Wenger, 1991). An example of this occurred during work on 'the golden ratio' when Melanie was absent for its introduction but was present the next day when her classmates had pictures and drawings of art works, buildings, etc. to illustrate their new learning. The following exchange occurred between her and two other students, James and Elaine, as they facilitated her active involvement in the ongoing investigation:

Melanie: What's this golden ratio?

James: It is a special rectangular shape that the ancient Greeks used in buildings and art mostly.

Melanie: So, it's a rectangle that only the Greeks used?

James: Well, not just them. Other people use it but the Greeks invented it. It's wider than it's high. See here *(showing her a picture and indicating length and width of the rectangle he has used to illustrate the golden ratio).*

Elaine: The sides are roughly in the proportion 2:3. (*Pause. She sees that Melanie is still confused and draws a rectangle in her copy to show her).* See…if you measure here, 2 cm and here, 3 cm, that's roughly it. *(Pause)* If you divided 3 by 2 you get 1.5 so you can write the ratio 2:3 also as ... 1:1.5.

Melanie: So, it's always 2:3 (*pause).* But, not every rectangle will measure 2 cm by 3 cm.

Elaine: That's true, but you can measure any rectangle and divide the long side by the short side and if you get around 1.5, then it may be the golden ratio. Well, there's a more accurate ratio, which is *(pause as she looks it up)* 1.618. We calculated it yesterday but I find it easy to remember the golden ratio using 2:3.

James: *(Showing her his picture again)* Look…If you measure the length and breadth of this section it fits the golden ratio. The length is 11 cm and the width is 6.5 cm. Now divide 11 by… 6.5 *(using calculator)* … that gives ... 1.692 which is nearly 1.618, so it's very near 1: 1.6

The example also shows Elaine and James as providers of knowledge with Melanie accepting their changed roles by not referring her questions to the teacher. Notice how the more capable peers move from a general explanation of the golden ratio being 'wider than it's high' and of ratio 2:3 to the more accurate ratio of 1.618, and its calculation. Throughout the episode Melanie's threshold of knowledge is carefully and continually assessed by them, as they scaffold her understanding incrementally with further facts while allaying her misapprehensions. The roles of more able peers or adults, together with social and linguistic influences on learning are important factors in Vygotsky's measure of the learner's development relative to instruction. His description of how the more knowledgeable person helps the less knowledgeable learn and reach higher conceptual levels than he or she would be unable to reach unassisted is known as "the zone of proximal development" (ZPD) (Vygotsky, 1978, p.86). Such instances of scaffolding of knowledge happened frequently as the TY classroom methodology progressed to being more pupil-centred than teacher-centred in orientation.

As students worked in groups co-constructing knowledge, classroom questioning helped assess students' thresholds of knowledge, incorporate their real-life experiences and guide them to new understandings. During the lead up to the following exchange, tossing a coin 10 times resulted in three heads and seven tails, though they had expected five of each. By exploring this together, they continued in a process of meaning-making and applying their knowledge to betting.

Teacher: What does a probability of $\frac{3}{10}$ mean?
Student 1: There are three out of ten chances of something happening.
Teacher: Would you consider that the event would be unlikely, likely or very unlikely?
Student 1: Unlikely … though not very unlikely.
Teacher: Why do you say that?
Student 1: Well, if it were $\frac{1}{10}$ it would be very unlikely as there is only one chance in ten it might happen, whereas with $\frac{3}{10}$, there are three chances out of ten, which is more likely than $\frac{1}{10}$...
Student 2: It's like horses. You can bet on them if you think there's a chance they'll win a race.
Student 3: How would you know from the betting that a horse might win?
Student 2: Short odds like …five to four or… two to one.
Student 2: But that shouldn't mean they'll win. If there are 5 horses in a race then each one should have $\frac{1}{5}$ chance of winning.
Student 3: Right, but if a horse won his other races or now has Ruby Walsh as jockey he may have a better chance of winning.
Student 2: Oh…so his chance would improve from $\frac{1}{5}$ to say $\frac{2}{5}$ or higher…

Throughout this meaning-making exchange, classroom questioning is an important tool with both teacher and students questioning and "more knowledgeable peers" answering. It embeds contextualised learning, creating deeper meaning and helps students tease out the symbolic representation of the language used. Formal mathematical language may not make sense as it is not used in their day-to-day activities so it may inhibit their mastery of the subject. Social exchange enables them to see that words (or symbols) hold the key to meaning allowing them to think, abstract, problem-pose and problem-solve. One of the students said later "I hadn't seen much point in the maths we had in Junior Cert., whereas now I see their value – how they can be used." Here he indicates that he values meaning-making in mathematics rather than just getting the right answer (Barab and Plucker, 2002). Conceptual development in mathematics then depends on such meaning-making with students actively participating in the process and connecting knowledge to the real-world.

The process of change from teacher-centred to student-centred mathematics was not straightforward (Conway and Artiles, 2005). Both teacher and students had difficulty in forsaking conventional exposition and practice style classroom teaching and learning and in adopting a suitable framework to guide and support their 'reformed' work. The teacher had to learn to cope with the students' transition of looking to each other for information and knowledge, rather than to her. To assist in this regard she employed classroom formations which enabled her best to draw out their knowledge to the point where either she or the students could progress investigations. Initial difficulty in managing student groups abated, as she recognised when to move in and out of the group in order to facilitate learning. A model she aspired to was Nathan and Knut's (2003) image of the teacher being the "guide on the side" (p.176), one who elicits and engages students' thinking, listens carefully, asks questions, monitors conversations, and decides when to step in and when to step aside. The accompanying classroom noise of students learning socially required adjustment too as she came to accept it as essential to an active community of learners – this ran counter to her 'lived' experiences as a traditional teacher. As these and other challenges were encountered and managed, the teacher experienced greater confidence and a satisfying sense of achievement.

In order to facilitate group work, the teacher arranged the furniture before students' arrival to the classroom. Students then knew at the outset whether they were being asked to collaborate in pairs, in groups, or as a class, thereby helping to focus students on the learning objective(s) for the class period (Gutiérrez *et al*, 1999). On arrival, and observing say, four chairs arranged around each desk, they would remark "we're in groups today" and were free to sit where they felt comfortable in gender balanced groupings facilitated by the teacher. Students themselves advocated collaborative learning with comments such as "we liked working in groups, because if one of us didn't understand something, another student explained it." During the settling in period to the class, their teacher usually shared information on proposed activities. This was a valuable exercise and an important space for probing new ideas as is illustrated here:

Students: *(As they enter the classroom)* What are we doing today Miss?
Teacher: We're going to look at ways of displaying data. You're familiar with statistics and the methods used there.
Student 1: Oh, you mean bar charts, trend graphs and … I can't remember what else.
Student 2: Are histograms the same as bar charts or are they different?
Student 1: Oh yeah, one has spaces between the bars, the other hasn't. Isn't that right?
Student 3: Then there was one with a curve…what was it? That had a name …cum … something…
Student 4: That's cumulative frequency. I liked that last year. It was shaped like an 'S'.
Student 5: There were others we had in national school that were up and down…to show things like sales of ice-cream.
Student 6: Can we look at them on the Internet?

While listening to initial exchanges among these active learners, the teacher discovered, to some degree, their interests and former knowledge so that she might incorporate them where possible in present or future learning experiences. In this way she learned about their world and found ways to align it to mathematical knowledge, this being especially helpful during the initial period of the study. For her it helped foster change in her personal / professional approach to, and management of, the reform-oriented classroom. Over time, both students and teacher became more adept in dealing with new ideas, and incorporating them into the learning process.

On the learning journey of reform mathematics, students were challenged in many ways, yet they found and welcomed new ways to respond to demands. Their dependence on the teacher's approval of their decisions and actions before initiating steps towards problem-solving was eventually replaced by a sense of critical confidence in their own decisions. Their initial hesitance to adopting different lines of inquiry to progress investigations moderated as they posed and discovered answers to their own questions. Their long-held belief of the teacher or the text book as being the source of all knowledge in the classroom faded as they began to articulate and value their own thinking. With their enjoyment of the social context of learning their difficulty in adapting to group work soon faded. Working independently too, they learned new skills such as compiling articles, surveying, testing hypotheses, accessing, deciphering and presenting information, etc. A satisfying sense of self worth developed through collective knowledge-building and respecting each other's views (Penuel and Wertsch, 1995). Their confidence grew as their contributions were valued by the teacher and as they learned to question the beliefs of others. They developed a sense of responsibility for their own learning by managing related classroom tasks and providing their own curriculum input. It was clear to us that the students formed a community of learners as they themselves became distant from traditional classroom practice.

CONCLUDING REMARKS

It is clear that the teaching and learning plan grounded in sociocultural theory had positive effects on TY students' mathematical applications. It is clear too that students' identities had shifted in accordance with this newfound 'way of knowing'. A new 'way of being', we witnessed, had been fostered. Varied classroom methodology engaged their active participation while reflective questioning helped them draw out information and formative assessment enabled them to recognise gaps in their learning and practical steps towards their remediation. During the evolutionary process of drawing away from the traditional teaching methodology the teacher too had changed. Specifically, she assumed a renewed role as the main organiser and facilitator of a collaborative learning climate. Related identity change in students was apparent in: their engagement and interest in mathematics; their ability to defend their points of view and follow different lines of thinking; and their willingness to correct misconceptions and connect mathematics to the real world. Such advancement of students as critical independent learners is in keeping with the teaching aspirations of Project Maths. Moreover, such change equips students well to a life replete with uncertainties and challenges. Transition Year, so aptly named, remains an important channel for encouraging and facilitating this inevitable change process.

Notes

- Project Maths is a new mathematics initiative which involves change of syllabus, assessment, teaching and learning of mathematics in Irish second level schools. In particular it aims to promote problem-solving and learning for understanding (see NCCA, 2012).
- 2 "The Spider and the Fly" problem was created by Henry Ernest Dudeney (1857 – 1930) and can be accessed at www.curiouser.co.uk

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Let´s Explore the Power of Candles

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There are many different phenomena that students come across every day. Depending on their interest they may observe them in detail or may not. Candle burning is an example of a phenomenon that everybody has already seen and watched. This common but rather complex phenomenon that involves a set of processes can be used as a good opportunity to develop skills to observe, formulate a problem, develop a hypothesis and plan investigations and hence can be built up to an inquiry activity to be carried out by students. The designed activity consists of three parts: Let´s explore the candle flame, Thermal power of the candle, Combustion heat of candle. Each part is completed with materials for teachers as well as worksheets for students' independent work. The materials are developed on the basis of the ESTABLISH project guide for developing teaching and learning units (ESTABLISH, 2014). The emphasise is laid on the active students´ approach during measuring and collecting data, peer discussion, gained results analysis with regard to students predictions and drawing conclusions. The materials are complemented with the pre-test aimed at gaining information about students' primal conceptual knowledge about the topic. The authors present experience and results of the implementation of the inquiry-based candle activity in the classroom at lower secondary school. Within the workshop the participants carry out the activity in parallel groups in a role of a student and discuss the inquiry skills development, its evaluation and implementation in different European school environment.

INTRODUCTION

Since 2006 we have been involved in preparing students for the Young Physicists Tournament (YPT). The problems that students are expected to solve are clear examples of higher level inquiry activities (Establish, 2010). Students are given a problem while the way how to solve it is completely up to them or the problems can be so open that even the concrete problem that is supposed to be investigated is up to the students to formulate. This aspect of the tournament requires mastering a set of inquiry skills of students who decide to take part at such a competition. That´s why it is very important to design methods how to conduct the students´ preparation and how to decide about the learning sequence where students go step by step in order to achieve the goal.

While preparing high school students for the Physics contest we regularly involve also University students – future physics teachers into this process. We use selected YPT problems as assignments for future physics teachers. The goal is to take the problem and based on it to design an activity to be implemented in the class. Students are expected to elaborate the outline of the learning sequence as if it was conducted during the lesson. One of the examples students have been working on is the problem of burning candle. Their approach to this problem and lesson design was mainly focused on the content knowledge (what does the candle consist of, how long does it burn, what is the temperature of the flame, how much heat is produced, how long does it burn, what is the combustion heat). Concerning methods students propose mainly traditional methods based on the transmission of knowledge from teacher to students when teacher explains the key concepts of the problem within a presentation. However, what students gain and learn from that is mainly content knowledge and skills connected with listening. Such students´ approach is a natural reflection of the way how they were and are being taught during their own lessons.

Different approach that we are trying to implement is to choose methods and strategies when students conducting the activity play a key role and there are directly involved in the process in order to develop not only content knowledge but also inquiry and reasoning skills. The learning sequence goes from observation through experimental design, formulating hypothesis, data collection and their interpretation, peer discussion, drawing conclusions based on evidence and sharing and defending the results. Our goal is to influence and persuade students about the benefits of IBSE to become their strategy of teaching in the future.

IDENTIFICATION OF PRIOR KNOWLEDGE

When conducting an inquiry activity, it seems to be very useful to get information about pre-existing knowledge that students have when they come to the classroom. Using a pre-test about the concepts of the activity gives information about the preconcepts that teacher can build on as well as it can draw students´ interest towards the subject of study. In case of candle burning activity we have developed several conceptual questions that students answer explaining also reasons for their response (Table 1)

Table 1: Items of pre-test on candle burning activity.

1. You have obviously seen how candle burns. What do you think the flame is created from? Describe your idea in your own words.
2. You have obviously seen how candle burns. What do you think the flame is created from? Describe your idea in your own words.
3. Imagine a candle flame. Think first and then answer: a. What is the flame temperature? Write down the temperature and describe how you have decided about this value. b. Is the candle flame temperature equal all over of the flame? Explain your answer.
4. Besides the burning candle you have certainly seen how wood or alcohol burner burns. Is there any difference between the burning of different materials? If so, what it is different? Explain your answer.
5. Mankind has been using flames to produce heat and light. Logically, bigger flame produces more heat than smaller flame. However, does the same-sized flame from different sources (e.g. alcohol burner and candle) produce the same amount of heat? Choose one of the following answers: a. Candle flame produces more heat than the alcohol burner flame of the same size. b. The alcohol burner flame produces more heat than the candle flame of the same size. c. Both same-sized flames from different sources produces same amount of heat. Give reasons for your answer.
6. When buying candles, you can usually find information about the length of burning on the label. The producers claim that their candle will be burning for 8, 12 or even more hours. What do you think the time of burning depends on? Choose one of the following answers:

a. Time of burning depends on the size of the candle. Bigger candle will be burning longer.
b. Time of burning depends on the size of the flame. Candle with smaller flame will be burning longer.
c. All candles have more or less equal-sized flames. Time of burning depends on the quality of candle material.

Give reasons for your answer.

The pre-test have been used at lower secondary class of 28 students aged 13-14 who answered the test about a week before the lesson. Here are the most frequent answers:

- The flame consists of fire, flammable gases, oxygen and wax.
- Estimated flame temperature is about 100°C.
- The flame temperature distribution along the flame is different; however students do not give reasons why.
- Different sources produce different flames; however there are no arguments for the answer presented.
- Alcohol burner produces more heat than that of the candle; however students do not give reasons why.
- Time of burning depends only on the amount of wax that the candle is made of.

The responses on the pre-test has shown that except from obvious lack of students´ knowledge in the field of burning there is also low level of argumentation skills of students. That made us think to put more emphasize on development of these skills, in particular.

INQUIRY ACTIVITY ON CANDLE BURNING

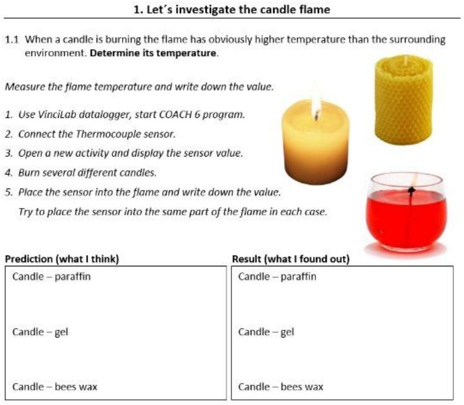
We have designed the candle burning activity as a guided inquiry activity when students investigate a teacher-presented question through a prescribed procedure. Students working in small groups of three are given a worksheet with step by step instructions that they follow. When measuring physical quantities, they use data logging tools (thermocouple and temperature sensor) and scales connected to the computer equipped with measuring and processing software (e.g. Coach). The activity is designed for 90 minutes (two school lessons).

Nevertheless, students before starting investigation can begin with observation of the phenomenon and formulating problems connected with it. They observe the flame, draw the picture of the flame, and describe what they noticed about the flame. We expect that they discuss the flame shape, different colours of different parts, candlewick burning, and hot air trembling around the flame, etc. Based on our experience from the classroom students mainly discuss why the flame shakes, what about its temperatures, how long the candle will be burning. Raising questions about candle burning can be supported by teacher-student dialogue when teacher help students to ask additional questions, e.g. How does candle start to burn?, What does the flame consist of, Is the temperature equal in different parts of the flame?, What is the difference between the flames produced by different sources?, What does the amount of heat produced by the flame (and time of burning) depend on?, Why do most candles produce some soot while cake candles do not leave any residue and burn cleanly with minimal soot?, etc.

Based on students´ formulated questions there can be the investigation plan designed. However, taking into account the time limitation and the current state curriculum in physics and availability of tools needed for experimentation we have developed three inquiry activities, i.e. Let´s investigate the candle flame, Thermal power of candle, Heat of combustion of candle.

Let´s investigate the candle flame

This part is aimed at formulating prediction about the flame temperature and verifying the prediction by taking data with the help of thermocouple connected to the computer.



1. Let´s investigate the candle flame

1.1 When a candle is burning the flame has obviously higher temperature than the surrounding environment. **Determine its temperature**.

Measure the flame temperature and write down the value.

1. *Use VinciLab datalogger, start COACH 6 program.*
2. *Connect the Thermocouple sensor.*
3. *Open a new activity and display the sensor value.*
4. *Burn several different candles.*
5. *Place the sensor into the flame and write down the value.*
   Try to place the sensor into the same part of the flame in each case.

Prediction (what I think)	**Result (what I found out)**
Candle – paraffin	Candle – paraffin
Candle – gel	Candle – gel
Candle – bees wax	Candle – bees wax

Figure 1: Example of students´ worksheet.

Thermal power of a candle

This part involves students into the discussion about the thermal power of a heat source. They are asked to search for information about thermal power of appliances that they use. Based on this information students are expected to estimate the value of heat produced by candle and give proposals how the thermal power could be measured using simple equipment. After discussing the measuring procedure students using temperature sensor connected to the computer measure the temperature change of the known amount of water heated by the candle, calculate the required value and compare it with their prediction.

$$P_{candle} = \frac{Q_{water}}{t_{heating}}$$

$$P_{candle} = \frac{c_{water}.m_{water}(t_2 - t_1)}{t_{heating}}$$

$$P_{candle} = \frac{4180J.kg^{-1}.K^{-1}.0,4\,kg.(29,6°C - 20,6°C)}{900s}$$

$$P_{candle} = \frac{15048J}{900s}$$

$$P_{candle} = 16,72\frac{J}{s} = 16,72\,W$$

Figure 2: Students measuring thermal power of a candle (left) and example of students´ calculations on thermal power of a candle (right).

Heat of combustion of a candle

The last part of the activity is aimed at determining the amount of heat of combustion, i.e. the amount of heat gained by burning one gram of paraffin. Firstly, they try to predict the value. In order to find out the value students investigate how quickly candle burns. Measuring the mass of a candle situated on the scales connected to the computer students find out how mass changes with time. Students are expected to use their skills to work with graph in order to gain the speed of burning. Knowing the thermal power as well as the speed of burning they can determine the amount of heat gained from burning one gram of paraffin.

$$Q_{combustion} = \frac{Q_{water}}{\Delta m_{candle}}$$

$$Q_{combustion} = \frac{c_{water}.m_{water}(t_2 - t_1)}{(m_1 - m_2)}$$

$$Q_{combustion} = \frac{4180 J.kg^{-1}.K^{-1}.0{,}4\,kg.(29{,}6°C - 20{,}6°C)}{(9{,}11g - 8{,}67g)}$$

$$Q_{combustion} = \frac{15048J}{0{,}44g} = 34{,}2\,\frac{kJ}{g}$$

Figure 3: Students measuring heat of combustion of a candle (left) and example of students´ calculations on heat of combustion (right).

EXPERIENCE FROM THE CLASSROOM

The activity was carried out by lower secondary class of 28 students aged 13-14. The classroom implementation has brought interesting information about the level of competencies and skills of students in conducting such activities. Based on direct experience from the classroom we can conclude:

- Searching for information skills are not sufficient, information provided by students are often very superficial
- Peer discussion must be strongly supported and encouraged by teacher, students cannot ask relevant questions, they have lack of communication skills in this field
- Students have problems in formulating predictions, they are used to write down what they are asked to do by teacher not what is the result of their own opinion
- Computer-aided measurement does not cause any major problems, students can handle the equipment easily
- Students are interested in presenting their ideas or group opinions in front of the class
- It is very important to revise what has been done during the lesson by the teacher and draw conclusions together with the whole class pointing to the most important facts

CONCLUSION

The design of inquiry activity on candle burning requires the active use of several inquiry skills, e.g. raising questions, conducting investigation, collecting, processing, analysing and interpreting data and drawing conclusions supported by peer discussion. Students proved to carry out the activity under the strong guidance from the teacher. We have identified a lack of skills mainly in the field of argumentation and peer discussion. Following from that teacher should put more emphasize on developing these skills of students while carrying out similar activities. With regular use of them students can surely improve towards more independent active learning.

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Lesson Study in Mathematics: Authentic Assessment of Inquiry Learning

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Classrooms are complex and unpredictable learning environments. Preparing future teachers to respond to the fast changing needs of learners in mathematics classrooms is the challenge of teacher educators. In our paper, we describe the structures we have put in place to support pre-service teachers move beyond being passive recipients of educational theories to becoming critical consumers capable of designing creative and innovative pedagogical approaches. Our approach to inquiry learning in mathematics takes the form of Japanese Lesson Study carried out in partnership with primary schools. Our presentation draws on data collected from 7 years of Lesson study research carried out with 140 pre-service teachers in 28 primary classrooms in Limerick city. Insights into inquiry teaching and learning of primary level mathematics will be provided by the display of video of classroom teaching of mathematics. Video of pre-service teachers reflecting on the process of engaging in inquiry learning is pivotal also to our presentation, in part, because the challenge for us as teacher educators continues long after our pre-service teachers teach their lessons. Our challenge is how to assess their developing understandings of mathematics and mathematics pedagogy? How do we attempt to capture the multiple and interconnected facets of good teaching and planning of mathematics? We share our efforts in assessing the learning of our pre-service teachers as they engage in planning for and teaching inquiry based lessons in mathematics. We report on our attempts to capture and assess learning through the focus on our students' ability to: engage in research, link pedagogical theories to classroom practice, work collaboratively in groups, design mathematics lessons, observe learners as they engage with mathematics, diagnose difficulties, respond flexibility and thoughtfully to classroom events and reflect on their own development of mathematics content knowledge and pedagogical content knowledge.

INTRODUCTION

Teaching mathematics for *understanding* is a complex task. Competence in mathematics requires that children construct rich conceptual understandings of mathematics, develop connections between procedures, concepts and representations, and engage in dialogue and discourse around mathematics. Supporting the construction of these competencies requires that teachers themselves have rich connected understandings of mathematics. In Initial Teacher Education (ITE) we expect pre-service teachers to be in the process of developing these understandings necessary to teach mathematics well. Assessing these developing understandings requires that teacher educators first identify the types of knowledge that are critical for the work of mathematics teaching, and then look for evidence of the presence of this knowledge within the pre-service teacher population.

Extensive research has been carried out to identify the types of knowledge required for effective teaching of mathematics resulting in the establishment of a number of different frameworks or models of teacher knowledge categorizing knowledge types. What all these frameworks illustrate is that the knowledge required to teach mathematics effectively is 'multi-dimensional' (Hill, Schilling and Ball 2004). This paper explores just two, of the many conceptualizations, of teacher knowledge – those of Shulman (1986) and Ball, Thames and Phelps (2008). The model proposed by Ball et al., has its foundations within Shulman's work, and was developed within the context of mathematics teaching; these factors influenced the selection of both these models as guiding framework in this study.

Shulman (1986) posits that teachers require three categories of knowledge. These categories are subject-matter knowledge (SMK), pedagogical content knowledge (PCK), and curricular knowledge. Subject matter knowledge refers to *'the amount and organisation of knowledge per se in the mind of teachers'* (Shulman 1986: 9). According to Ball et al (2008), subject matter knowledge is further categorised into *common* and *specialised* content knowledge. Common content knowledge involves knowledge of the mathematics school curriculum, for example being able to divide fractions. Specialised content knowledge is mathematical knowledge beyond the curriculum – it is the knowledge of mathematics specifically used for teaching.

The second type of teacher knowledge, PCK, focuses more exclusively on knowledge for teaching. Ball et al. categorise pedagogical content knowledge into *knowledge of content and students* (KCS) and *knowledge of content and teaching* (KCT). KCS "combines knowing about students and knowing about mathematics" (Ball et al. 2008). This type of knowledge includes knowledge of common student misconceptions, mathematics that is perceived as interesting or difficult, and common approaches used by children when presented with specific tasks. KCT provides teachers with the understandings required to plan their teaching so that misconceptions are challenged. This planning incorporates attention to the sequencing of instruction to address misconceptions and draws on useful examples to highlight misconceptions. KCT is also necessary to inform the design of a sequence of instruction that provides a trajectory of tasks which build in complexity and at a speed that provides sufficient consolidation of understanding.

Assessing SMK is generally carried out through the use of pen and paper tests. In contrast the assessment of PCK is less straightforward. The construction of assessment items to capture this knowledge is quite difficult, however, another approach is the observation of pre-service teachers as they teach in classrooms. This paper reports on the assessment of pedagogical knowledge of pre-service teachers as they teach, and reflect upon, the classroom teaching of mathematics.

METHODOLOGY

This study was carried out with 20 final year pre-service primary teachers during the concluding semester of their teacher education program. Participants had completed their mathematics education courses (three semesters) and all teaching practice requirements (at junior, middle and senior grades) and self-selected into mathematics education as a cognate area of study.

In this study, pre-service teachers (working in groups of 5-6), and three mathematics educators used *Japanese Lesson Study* (Fernandez & Yoshida, 2004; Lewis, 2002; Lewis & Tsuchida, 1998) to examine the planning and implementation of lessons in classrooms and thus facilitated the design of tools and sequences of instruction to support the development of statistical reasoning with primary children. Participants worked in five groups of 5-6 participants on the design and implementation of a study lesson. This paper examines the work of <u>one group working with senior infant pupils</u>.

The research was conducted over a 12-week semester. While the first phase involved the *research and preparation* of a study lesson i.e. researching the concept of function in order to construct a detailed lesson plan, the *implementation* stage involved one pre-service teacher teaching the lesson in a senior infants classroom while the remainder of the group and the researchers observed and evaluated classroom activity and student learning. Subsequently, following discussion, the original lesson design was modified in line with their observations. The *second implementation* stage involved re-teaching the lesson with a second different class of senior infants and *reflecting* upon observations. The second implementation was videotaped. This cycle concluded with each lesson study group making a presentation of the outcomes of their work to their peers and lecturers at the end of the semester.

This paper reports on the work of one lesson study group- the Senior Infants group, using their mathematics lesson as the unit of analysis. The data illustrate how observation of classroom teaching sheds insights into the PCK demands placed on pre-service teachers when teaching primary level mathematics.

RESULTS

Illustration of ***KCT: Knowledge of Content and Teaching***

KCT was revealed across different lesson components. Knowledge of content and teaching supports teachers when *designing the sequencing of the content of instruction* (Ball et al. 2008). Pre-service teachers carefully designed the sequence of instruction to build in complexity. Initial lesson stages provided opportunities for pupils to develop experience in collecting data (Figure 1). This data collection activity build the knowledge needed for later activities (Figure 2).

Figure 1

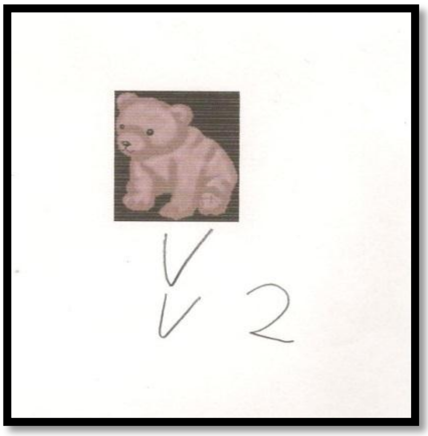

Figure 2

KCT is also revealed through the *selection of models, representations and procedures that support the development of mathematical understandings* (Ball et al. 2008). Pre-service teachers encouraged the construction of concrete graphs of data in an effort to support the developing understandings of data representation on graphs (Figure 3). This indicated their awareness of the difficulties young pupils experience with data abstraction and represented a solution as presented in each data value being represented by a unifix cube. These graphs provided as the precursor to the pictogram constructed by the teacher in conjunction with the class (Figure 4).

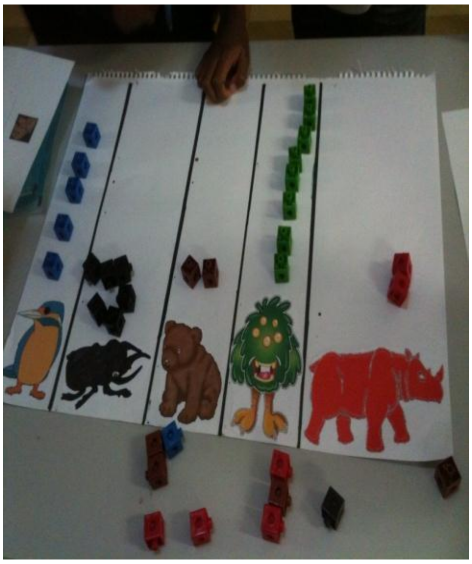

Figure 3

Figure 4

Illustration of ***KCS: Knowledge of Content and Students***

The lesson provided evidence of KCS identified in a number of different lesson components. KCS is evidenced in the *ability to select exemplars that motivate and interest students* (Ball et al. 2008). Pre-service teachers wrote a story that engaged and motivated the 6 year old pupils and served as the focus of classroom instruction. Further evidence of KCS was evident in their *ability anticipate student misconceptions when presented with a mathematical task* (Ball et al. 2008). Pre-service teachers were aware of the difficulties children experience with the language of mathematics and had predicted that the use of the word 'more' in the question 'How many more times would red rhino have to come up in the story to beat Green Monster?' may cause confusion. They predicted that the word 'extra' was more accessible to children and used this to supplement meaning to the question (see transcript below). The transcript that follows refer to questions asked based on a pictogram representing the outcome of the data collection (image 4).

Teacher	How many more times would red rhino have to come up in the story to beat Green Monster? This is a really tricky one. How many more times … How many extra times would he have to come to beat Green Monster?
Girls voice	8
Teacher	Let's see …. Grace.
Grace	9
Teacher	9 more times. So if he came up 9 more times he'd have all these spaces filled and he'd be up to the roof nearly. Wouldn't he? But he doesn't have to come up 9 time to
Dara	5
Teacher	.. beat him

Dara	He has to come up 5.
Teacher	So if he had 5 more he'd be right up here. So he'd be tied. But we want him to beat Green Monster. So, how many times would he have to come up then?
Dara	5
Teacher	I wonder who can solve this one?
Girls voice	11
Teacher	11? It's not, it's smaller than 11. He would beat … If there was 11 he would definitely beat [Green Monster] but he doesn't have to come up 11 times. Not even that many. Kerry?
Kerry	23
Teacher	23! Oh we are coming up with very big numbers.
Dara	He would need to come up 6 more .. to beat him
Teacher	Super. Were you going to say that (speaking to another child). How do we know 6 more times?
Dara	Because it would be off the chart then
Teacher	It would be off the chart, it would be all the way up to Green Monster and then 1 above him.

Analysis of the transcript also reveals deficits in KCS, specifically around the ability to *interpret the mathematical meaning associated with student responses* (Ball et al. 2008). As can be seen, the pre-service teacher does not realize that the responses of 11 and 23 are correct. These values all satisfy the question criteria. The difficulty itself arose from deficits in KCT pertaining to the ability to *select appropriate mathematical language* (Ball et al. 2008). The intended question pertained to the least number of times that Red Rhino would have to occur to beat Green Monster, hence the only correct answer was 9. However the phrasing of the question did not indicate 'least', hence any value greater than or equal to 9 would suffice. Pre-service teachers had not realized this in their lesson design.

CONCLUSION

Lesson study serves as the vehicle wherein participants learn from engaging in and observing teaching; in contrast to traditional pedagogy courses where we just talk about teaching.

While primary teachers are generalist teachers and it is not expected that they are experts in every curricular area, Rowland et al (2009) highlights that teachers are expected to be 'knowledgeable' about their work. Policy makers concur that pupils would learn more mathematics if their teachers knew more mathematics (Kahan et al, 2002). Ball et al (2005: 14) proposes that it is not possible to contemplate improvement of pupils' mathematics achievement without focusing on the nature and effects of teacher practice, that is *'…no curriculum teaches itself…'*.

Lesson study has been found to facilitate pre-service teachers to be a helpful tool in translating the theories presented in traditional lecture-style pedagogy courses to classroom based pedagogical practices (Hourigan and Leavy, 2012; Leavy, McMahon & Hourigan, 2013).

In terms of assessment, while it is common place for instruments (using pen-and-paper assessments) to be developed and administered to gauge student and qualified teachers' knowledge for teaching, these approaches could be considered to be 'narrowly conceived'. It is difficult to ascertain the extent to which performance in an pen-and-paper instrument can provide a conclusive measure of a student teacher's level of preparedness.

In contrast, the nature of Lesson study where there is a particular emphasis on research and reflection provides a vehicle whereby pre-service teachers' knowledge can be examined and developed concurrently within the context of teaching lessons in 'live' classrooms. It facilitates the pre-service teachers themselves to develop the appropriate knowledge as well as making them aware of the shortcomings in their knowledge and the potential for further development. In essence it provides both 'assessment of learning' and 'assessment for learning'.

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An Analysis of the Opportunities for Creative Reasoning in Undergraduate Calculus Courses

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We report here on a study of the opportunities for creative reasoning afforded to first year undergraduate students. This work uses the framework developed by Lithner (2008) which distinguishes between imitative reasoning (which is related to rote learning and mimicry of algorithms) and creative reasoning (which involves plausible mathematically-founded arguments). The analysis involves the examination of notes, assignments and examinations used in first year calculus courses in DCU and NUI Maynooth with the view to classifying the types of reasoning expected of students. As well as describing our use of Lithner's framework, we discuss its suitability as a tool for classifying reasoning opportunities in undergraduate mathematics courses.

INTRODUCTION

In this project, we aim to study the opportunities for creative reasoning afforded to first year undergraduate students using the framework developed by Lithner (2008) to characterise different types of reasoning. He defines reasoning as 'the line of thought adopted to produce assertions and reach conclusions in task-solving' (Lithner 2008, p 257). His definition includes both high and low quality arguments and is not restricted to formal proofs. For this reason, the framework is useful in studying the thinking processes required to solve problems in calculus courses, where often proofs are not given or required but students are expected to make plausible arguments and conclusions. Lithner distinguishes between *imitative reasoning* (which is related to rote learning and mimicry of algorithms) and *creative reasoning* (which involves plausible mathematically-founded arguments). In this project, we use this framework to classify the reasoning opportunities available in a range of first year calculus modules offered in DCU and NUI Maynooth. We are considering both courses for specialist and non-specialist students, as well as compulsory and non-compulsory modules. (Note that by specialist students we mean students who intend to take a degree in mathematics, while courses for non-specialists are often called service courses.)

Studies have shown (for example Boesen et al. 2010) that the types of tasks assigned to students can affect their learning and that the use of tasks with lower levels of cognitive demand leads to rote-learning by students and a consequent inability to solve unfamiliar problems or to transfer mathematical knowledge to other areas competently and appropriately. It is therefore important to investigate whether first year students in our universities are given sufficient opportunities to develop their reasoning and thinking skills. This research is particularly timely given the current focus on how best to foster critical thinking skills in undergraduate students (HEA & NCCA 2011). The development of mathematical reasoning and thinking skills is also crucial for prospective mathematics teachers, whose work demands much more than rote-learning of mathematical procedures (Ball, Thames and Phelps 2008).

In this paper, we will outline the framework used in our analysis and give some examples of the classification of tasks from the courses under review.

LITERATURE REVIEW

Transition to university is widely acknowledged as a difficult process and students often find that the transition in mathematics is especially problematic (Clarke and Lovric 2009). Students' difficulties in first year seem to stem from the new thinking skills and levels of understanding expected of them (Gueudet 2008). Students grapple with notions such as function, limit, the role of definitions, and rigorous proof. These topics are encountered by millions of students worldwide including engineers, scientists, future teachers, as well as mathematics specialists. It is often said that the study of mathematics promotes the development of thinking skills, indeed Dudley (2010) states that the purpose of mathematics education is to teach reasoning. However, there is a sense of unease amongst some commentators that students 'can pass courses via mimicry and symbol manipulation' (Fukawa-Connelly 2005, p. 33) and that most students learn a large number of standardised procedures in their mathematics courses but not the 'working methodology of the mathematician' (Dreyfus 1991, p. 28) and thus may not develop conceptual understanding or problem-solving skills. Some studies have been carried out, notably in the UK and in Sweden, to investigate if there is evidence for these comments. Pointon and Sangwin (2003) developed a question taxonomy to classify a total of 486 course-work and examination questions used on two first year undergraduate mathematics courses. They concluded that:

> (i) the vast majority of current work may be successfully completed by routine procedures or minor adaption of results learned verbatim and (ii) the vast majority of questions asked may be successfully completed without the use of higher skills (p.8).

In Sweden, Bergqvist (2007) used Lithner's framework to analyse 16 examinations from introductory calculus courses in four universities. She found that 70% of the examination questions could be solved using imitative reasoning alone and that 15 of the 16 examinations could be passed without using creative reasoning.

Recent studies in Ireland (Lyons, Lynch, Close, Sheerin, and Boland 2003, Hourigan and O'Donoghue 2007) have found that procedural skills are emphasized in second level classrooms and that technical fluency is prized over mathematical understanding. This can lead to problems when students progress to third level (Hourigan and O'Donoghue 2007). In this study, we aim to investigate whether assessment in first year undergraduate courses in Ireland resembles that of Sweden and the UK and if the emphasis on procedures and algorithms at second level persist in university modules.

CONCEPTUAL FRAMEWORK

In this project a *task* will be any piece of student work including homework assignments, tests, presentations, group work etc. Lithner (2008) distinguishes between imitative and creative reasoning. Imitative reasoning (IR) has two main types: memorised (MR) and algorithmic (AR). In order to be classified as MR a reasoning sequence should have the following features:

1. The strategy choice is founded on recalling a complete answer.

> 2. The strategy implementation consists only of writing it down. (Lithner 2008, p. 258)

This type of reasoning is seen most often at the undergraduate level when students are asked to recall a definition or to state and prove a specific theorem. Algorithmic reasoning is characterised by

> 1. The strategy choice is to recall a solution algorithm. […]
>
> 2. The remaining reasoning parts of the strategy implementation are trivial for the reasoner, only a careless mistake can prevent an answer from being reached. (Lithner 2008, p. 259)

Lithner calls a reasoning sequence creative if it has the following three properties:

> 1. Novelty. A new (to the reasoner) reasoning sequence is created, or a forgotten one is re-created.
>
> 2. Plausibility. There are arguments supporting the strategy choice and/or strategy implementation motivating why the conclusions are true or plausible.
>
> 3. Mathematical foundation. The arguments are anchored in intrinsic mathematical properties of the components involved in the reasoning. (Lithner 2008, p. 266).

The creative reasoning (CR) classification can be further divided into two subcategories: Local creative reasoning; and Global creative reasoning. A task is said to require local creative reasoning (LCR) if it is solvable using an algorithm but the student needs to modify the algorithm locally. A task is classified in the global creative reasoning (GCR) category if it does not have a solution that is based on an algorithm and requires creative reasoning throughout (Bergqvist 2007). We note that some minor adjustments to the framework were found to be necessary. These are discussed below.

METHODOLOGY

In this study we classify tasks from four first year calculus courses; two at DCU and two at NUI Maynooth. The courses include a business mathematics module, two modules for science students, as well as a module for pure mathematics students. These four modules span the range of first year calculus courses offered to students in Ireland.

The data in this project consist of the following types: lecture notes, textbooks, assignments, examination questions. We collected all the relevant information with the cooperation of the module lecturers. The data analysis of each module is currently being carried out by two independent researchers from the research team who do not work in the home university of the module. This inter-rating approach will ensure reliability of the analysis of the course material from the different modules (see e.g. Chapter 5 of Cohen, Manion and Morrison (2000)).

We began the analysis by classifying exercises from a calculus textbook, in order to gain some experience and to discuss and agree on our classification methods. All four of the authors classified these sample tasks independently and then met to finalize our procedures. These procedures are in line with those presented by Lithner (2008) and Bergqvist (2007). The researchers first construct a solution to the task and this is then compared to the course notes and textbook examples. Using Lithner's framework, the researchers decide whether the task could be solved using imitative reasoning or whether creative reasoning is needed. We found that the most difficult decisions concerned the classification of tasks into the LCR or GCR categories, and so we adapted the framework in the following way: In order to be consistent we decided that we would classify a task as LCR if the solution was based on an algorithm but students had to modify one sub-procedure. We decided to classify a task as GCR if two or more sub-procedures were new, if a proof aspect was the novel element, or if mathematical modeling was the novel element.

EXAMPLES

In this section we will present some examples of tasks classified using the Lithner reasoning framework. We will concentrate on one topic in order to be coherent and to be better able to compare categories. We will consider the topic of quadratic equations, which is important in many calculus and pre-calculus courses.

In the course in question, the lecture notes and the textbook (Jacques 2009) discuss solutions of quadratic equations using the quadratic formula as well as factoring, and give examples which illustrate both methods. The questions below are taken from the exercises in Section 2.1 of the text and were assigned as tutorial problems by the lecturer.

Task 1*: Solve the following quadratic equations, rounding your answers to 2 decimal places, if necessary:*

(a) $x^2 - 15x + 56 = 0$*; (b)* $2x^2 - 5x + 1 = 0$*; (c)* $4x^2 - 36 = 0$*;*
(d) $x^2 - 14x + 49 = 0$*; (e)* $3x^2 + 4x + 7 = 0$*; (f)* $x^2 - 13x + 200 = 16x + 10$.

Task Analysis:

Solution method: Students could use the quadratic formula or factorization here. The solutions are:

a) $x^2 - 15x + 56 = (x-7)(x-8)$, so the solutions are $x = 7{,}8$;
b) using the quadratic formula we have $x = \frac{5 \pm \sqrt{17}}{4}$, so to 2 decimal places $x = 2.28, 0.22$;
c) $4x^2 - 36 = 4(x-3)(x+3)$, so the solutions are $x = -3, 3$;
d) $x^2 - 14x + 49 = (x-7)^2$, so there is just one solution at $x = 7$;
e) using the quadratic formula we have $x = \frac{-4 \pm \sqrt{-68}}{6}$, so there are no real solutions;
f) subtracting $16x + 10$ from both sides gives $x^2 - 29x + 190 = 0$ and since $x^2 - 29x + 190 = (x-10)(x-19)$, the solutions are $x = 10, 19$.

Text Analysis:

- *Occurrences in the notes*: The quadratic formula is given on page 14 of section 2.1 and it is used in examples on pages 16, 17 and 18 of that section. The factor method and an example can be found on page 19. Examples of rearrangements similar to (f) occur on pages 18 and 29.
- *Occurrences in the text*: The quadratic formula can be found on page 132 of the textbook and it is used in examples on pages 132, 133 and 134. The factor method is explained on pages 134 and 135 of the book and used in examples on page 135. An example on page 141 includes a rearrangement similar to part (f).

Argument and conclusion:

This is an Imitative Reasoning (IR) task, specifically it is an Algorithmic Reasoning (AR) task. The students just need to use the algorithms from the notes and the textbook.

Task 2*: Write down the solutions to the following equation:*

$$(x-2)(x+1)(4-x) = 0.$$

Task Analysis: Solution Method: Since $(x-2)(x+1)(4-x) = 0$, we conclude that $x = 2, -1{,}4$.

Text Analysis:

- *Occurrences in the notes*: The factor method and an example can be found on page 19, but there is no example with three factors.

- *Occurrences in the text*: The factor method is given on pages 134 and 135 of the book and used in examples on page 135; however the examples do not cover the case of three factors.

Argument and conclusion:

This is a Creative Reasoning (CR) task, specifically it is a Local Creative Reasoning (LCR) task. The students can use the factor method algorithm from the notes and the textbook however they need to modify it to handle the three factors.

Task 3*: One solution of the quadratic equation*

$$x^2 - 8x + c = 0$$

is known to be $x = 2$. *Find the second solution.*

Task Analysis:

Solution Method: Since $x = 2$ is a solution, we can see that $2^2 - 8(2) + c = 0$, i.e. $c = 12$. Using this, we can solve $x^2 - 8x + 12 = 0$ using either the factor method or the quadratic formula to get that the second solution is $x = 6$.

Text Analysis:

- *Occurrences in the notes*: The factor method and the use of the quadratic formula can be found in the notes; however there is no example of this type there.
- *Occurrences in the text*: There are examples using the factor method and the quadratic formula in the text but there is nothing similar to this question.

Argument and conclusion:

This is a Creative Reasoning (CR) task, specifically it is a Global Creative Reasoning (GCR) task. The notes and textbook do not contain an algorithm that the students can follow; they need to create a new mathematically plausible strategy to find the value of *c*.

DISCUSSION

We note first that the analysis of all tasks for the different courses has not yet been completed. Thus we cannot yet discuss the proportions of tasks in each category or compare modules; this will be reported on at a later date.

Of the tasks classified to date, we have not found any that lie in the MR (Memorised Reasoning) category. It will be of interest to see if this category appears in exams.

As noted above, the classification is not always straightforward, especially when deciding between LCR and GCR. Similar difficulties arise in distinguishing between AR and LCR. For example, it can be difficult to decide whether a reasoning element should be regarded as novel or not: this can be subjective. In order to counteract this, the inter-rating approach was used, with clear guidelines agreed on categorization and the use of discussions to resolve borderline cases. It was also found necessary to amend Lithner's framework slightly in order to fit our purposes.

A further difficulty is that we do not know what other learning experiences the student has had – for example in secondary school, in tutorials, in Mathematics Learning Support Centres, etc. We can only classify tasks using the information we have from the notes and textbook. This is a possible weakness in the study. However, it should be noted that this difficulty mirrors the situation in which the lecturer finds him or herself: they must make decisions on teaching and assessment in the absence of detailed knowledge of their students' prior learning experiences.

Classifications like this can help us as lecturers to make sure we balance our assignments and examinations to ensure that students are presented with an appropriate variety of reasoning tasks, and to avoid an over-emphasis on rote-learning tasks. The results of the full analysis will provide us with a detailed picture of the reasoning opportunities available to first year calculus students in our courses. By highlighting this process, we hope to provide a useful tool for other mathematics lecturers involved in curriculum design.

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Using Interactive Demonstrations at Slovak Secondary Schools

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There is an educational reform running in Slovakia from 2008. In science education it emphasizes active independent learning of students based on inquiry teaching and learning strategies. The main emphasize has shifted from the mainly content-based learning towards the development of inquiry skills and 21st century skills connected with critical and creative thinking. In order to create active learning environment in the classroom there can be different methods used. One of the strategies developed in order to fulfill this goal is interactive lecture demonstrations ILD (Thornton, Sokoloff, 2004, 1997). It combines traditional lecture-based lesson with active-learning computer-based laboratory tools with one computer in the class. Teacher carries out simple short experiments enhanced by digital technologies while students using predictions and discussions with classmates and teachers are led through a series of tasks to understanding the physical concepts and phenomena in order to draw reasonable conclusions. The ILD method has been adapted and implemented in a grammar school in Slovakia for several school years (2008 - 2014). The unit of mechanics has been taught with the support of a series of interactive demonstrations concerning motion and concepts of position, velocity, acceleration, force, energy and laws of motion. The results of students´ predictions as well as the results achieved at the end of the unit were monitored in order to compare the experimental class (using ILD) and the other class (using traditional approach). Assessments of the gained results have indicated that student understanding of concepts has improved in most cases compared to students of traditional class. Analysis of their predictions revealed some problematic areas of their conceptual understanding. Nevertheless, this method forces them to be actively involved in the process of thinking and reasoning, students are led to mutual discussion, but also listening to their peers and cooperation within the group. It gives students the possibility not only to learn, but above all to think and explore actively and independently and so better understand the physical phenomena and the process of inquiry.

INTRODUCTION

There is an educational reform running in Slovakia from 2008. In science education it emphasizes active independent learning of students based on inquiry teaching and learning strategies. The main emphasize has shifted from the mainly content-based learning towards the development of inquiry skills and 21st century skills connected with critical and creative thinking. In order to create active learning environment in the classroom there can be different methods used. One of the strategies developed in order to fulfill this goal is interactive lecture demonstrations ILD (Thornton, Sokoloff, 2004, 1997). This strategy originally developed to support conceptual understanding of introductory physics courses at Universities has been also successfully implemented at secondary schools. The interactive demonstration method has been adapted and implemented in a grammar school in Slovakia for several school years.

METHODOLOGY

The interactive lecture demonstration method has been originally designed for University lectures in order to engage students in the learning process and, therefore, convert the usually passive lecture environment to a more active one. It is based on implementing a series of simple short experiments usually supported by computer-based laboratory tools conducted by teacher. Experiments are carried out in a succession of several steps listed in table 1.

Table 1: The 8-steps interactive Lecture Demonstration Procedure (Thornton, Sokoloff, 2004)

1. The instructor describes the demonstration and does it for the whole class without measurement displayed.
2. The students are asked to record their individual predictions on a Prediction Sheet and discussions with their one or two nearest neighbors.
3. The students engage in small discussions with their neighbours.
4. The instructor elicits common student predictions from the whole class.
5. The students record they final predictions on the Prediction Sheet.
6. The instructor carries out the demonstration with measurements displayed on a suitable display (e.g. overhead projector).
7. A few students describe the results and discuss them in the context of the demonstration.
8. Students (or the instructor) discuss analogous physical situations based on the same concepts.

Students are given prediction sheets in order to record their prediction that is collected and used by teacher in order to identify pre-knowledge and misconceptions. The final correct results based on the measurement are recorded to the Result sheet that is kept by students. There has been a large-extent research carried out on the effectiveness of ILD in conceptual understanding of concepts of selected units (e.g. Sokoloff, Thornton, 1997, Sharma et al., 2010, Loverude, 2009). The results of research indicate that students´ understanding of concepts has been improved when ILDs are implemented.

Getting inspired by the ILD method and research results the method has been adapted and implemented in a grammar school in Slovakia. There were selected experiments on motion translated and adapted to the conditions of the Slovak physics curriculum. These experiments have been implemented in the unit of Mechanics taught at the 1st grade of upper secondary school (students aged 15-16) during several school years (2008-14). The experiments were aimed at Human uniform motion, Uniformly accelerated Motion of carts, Newton´s 1st and 2nd laws, Newton´s 3rd law, Energy of a cart on a ramp. All the experiments were based on measuring position, velocity, acceleration, force with the help of data logging tools and presenting graphical representations of motion for the whole class. The results of students´ predictions as well as the results achieved at the end of the unit were monitored in order to compare the experimental class (using ILD) and the other class (using traditional approach).

RESULTS

The implemented experiments were aimed at conceptual understanding of the concepts of position, velocity, acceleration, force, energy and laws of motion. Here are some of the results gained and misconceptions identified and analyzed during the implementation.

Examples of misconceptions in mechanics

1. Students basically did not have problems in drawing position vs. time graphs for uniform motion. Students had more problems in velocity vs. time graphs, with motion toward the detector and with correct sign of corresponding velocity, in particular. Surprisingly, the score for drawing a prediction of velocity graph for a person who does not move was the one with the lowest gain.
2. When it came to accelerated or decelerated motion from the detector, the predictions concerning velocity were quite satisfactory. The problems arose when the cart moved towards the detector when the score decreased significantly. The most problems were identified in drawing acceleration for the experiment in fig.1, at the moment when the direction of motion changed, where none of the students predicted the result correctly. However, for this level of students the problem with opposite motion experiments and drawing corresponding graphs are quite demanding and confusing, so as a result we have omitted these experiments in the next years concentrating on correct understanding of motion from the detector only.

5. A cart is subjected to a constant force in the direction away from the motion detector. Sketch on the axis your predictions of the velocity-time and acceleration-time graphs of the cart after it is given a short push toward the motion detector. Sketch the velocity and acceleration as the cart slows down moving toward the detector comes momentarily to rest and then speeds up moving away from the detector.

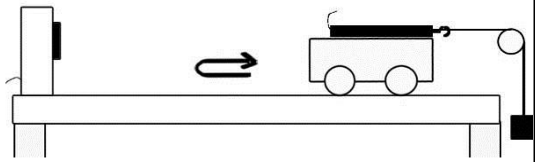

Figure 1: Example of experiment on accelerated motion of a cart.

3. In the experiments on 1st and 2nd Newton´s law students formulate predictions on the motion under constant force. When comparing two motions, one under the influence of external force (weight hanging on a thread connected with the cart) measured by the sensor neglecting friction and the other one under the same external force but using the friction pad that increases the friction significantly, many students have sketched the applied and the net force with the same value. A lot of wrong force vs. time predictions appeared in the same experiment as in fig. 1 when the applied force was measured and expected to be sketched. Most students drew a graph with changing shape at the moment when the cart comes to the rest and moves away from the detector.
4. In the experiments on 3rd Newton's law students were surprised a lot about the fact that if a hand pushes a cart, the cart pushes the hand with the same force, even if the cart moves at constant velocity or accelerates or decelerates (fig.2).

6. The block is being pushed *at a constant velocity* (*so that it slows down/speeds up*). How do the force $F_{H\text{-}B}$ (Hand on Block) and $F_{B\text{-}H}$ (Block on Hand) compare?

Figure 2: Experiment on 3rd Newton's Law

Effect of ILD on conceptual understanding of the concepts of mechanics

In order to show the effect of ILD in the unit of mechanics we have used pre and post-tests in experimental and traditional classes. All the classes have been taught by experienced teachers. For that purpose we have used selected questions from FCI (Halloun et al.) and FMCE (Sokoloff, Thornton, 1998) conceptual tests. Using identical pre and post-tests we have compared the normalized gain. In the evaluation of results we included only those students who answered both tests. Selected classes results are in tab.2 and fig.3.

Table 2: Comparison of results gained in traditional and experimental classes.

Years	**Class**	**Numb of students**	**Pre-test**	**Post-test**	**Normalized gain**
2009/10	**Experim. class (1.D)**	28	34,82%	88,39%	82,19%
2010/11	**Traditional class (1.B)**	23	32,61%	71,74%	58,06%
	Traditional class (1.C)	24	48,96%	67,71%	36,73%
	Experim. class (1.D)	27	43,52%	82,41%	68,85%
2011/12	**Experim. class (1.C)**	27	23,15%	85,19%	80,72%

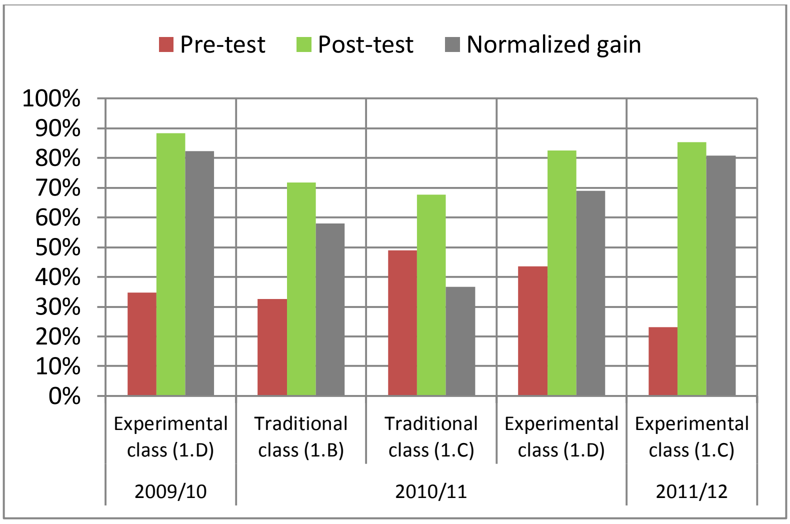

Figure 3: Comparison of results gained in traditional and experimental classes

CONCLUSIONS

From the presented results it can be seen that the experimental classes have achieved much better results than the classes taught without the use of ILDs. This result gives us motivation for the continuous use of ILDs. However, there are several rules that should be followed for effective results. Teacher has to prepare all the experiments and the technologies needed very carefully, when technological problems appear, the students´ attention is distracted. At one lesson, teacher should carry out just a few short experiments (2-3). Following these rules, the method can bring significant results in conceptual and graphs´ understanding.

We see the main reason in the fact that the method forces students to be actively involved in the process of thinking and reasoning; students are led to mutual discussion, but also listening to their peers and cooperation within the group. Such approach gives students the possibility not only to learn, but above all to think and explore actively and independently and so better understand the physical phenomena and the process of inquiry.

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Cognitive Acceleration in Primary Science Teacher Education: catching-up at third level

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The Cognitive Acceleration through Science Education, i.e., CASE, or Thinking Science, i.e., TS, programme, developed originally in the mid-1980's in UK, has been shown to be effective in increasing students cognitive levels in Ireland as well as elsewhere in the anglophone world. Previous studies have focussed on implementation of CASE with particular class groups of children in primary or secondary school, the development of teachers to implement CASE in primary school with particular attention to metacognition, or the transition from primary to secondary school. In this work, the relevence of thinking skills to the primary curriculum is portrayed, and a discussion of the current emphasis in skills in general in science education by stakeholders. It is argued that skills education requires a different kind of learning, and therefore teaching, and that young adults who plan to be primary teachers are in a deficit of thinking skills as they are still channelized by a content driven school system. A CASE-based initial teacher education framework is proposed.

SCOPE AND PURPOSE

The purpose of this paper, which is part of long-term on-going work in encouraging thinking skills in children, is to cause stakeholders in primary level science education to reflect. The reflection being sought is on the preparation of primary level teachers of science, thinking about how much we should expect them to know, what kind of knowledge they should have, and how we can rectify deficits in skills and understanding. To be honest, the question is not new, but stakeholders are apt to fudge such questions in order to realize short-term goals: Wynne Harlen in a UNESCO report from 1993, and repeated in many books since, even titled a chapter on this very point (Harlen, 1993).

INTRODUCTION

The aphorism "*Teachers should know more than the children they teach*" implies that knowing is merely a matter of quantification, in which case, the better teacher would be someone who 'knows more' than others. In some areas, such as science and ICT, children often 'know' things that teachers do not as yet know thanks to the availability of various information media. In the past, when such information media were not available, it could be guaranteed that teachers adopted to role of 'sages' and *'fountains of all wisdom and knowledge'*, pillars of the community, the first to own a telephone, car, or television. The first to receive the signs that the world was changing, the last perhaps to embrace the change in their workplace. For the purpose of this paper, i) 'knowing' is simply the acquisition of facts and concepts; ii) 'understanding' is more complex, involving networks between concepts and varying degrees of structuralisation and complexity; iii) 'wisdom' is the deployment of knowledge and the employment of understanding in contexts that are different from those in which the 'knowing' arose, or the 'understanding' originally was intended.

Figure 1: Over-simplified model of cognitive architecture – are any of the areas of the Venn diagram null?

It is important to note that although this three-fold list appears to be a hierarchy, it does not presume that one leads to another in a linear fashion. In fact, the three 'spheres', namely: knowledge, understanding, wisdom, involve manifold feedback mechanisms cutting across various domains. Furthermore, one can have knowing or understanding with/without wisdom and skills can cut across the three spheres as a floating entity as required. Skills acquisition could involve acquiring specific knowledge, and knowledge requires 'skills' in order to develop. What has been outlined thus far is a rather over-simplified cognitive architecture; however, the problem this work attempts to address is the emphasis on knowing without understanding or wisdom that is encouraged in the Irish education system today. Of all the interventions that developed out of the science education revolution of 1970s, the Cognitive Acceleration through Science Education, i.e., CASE, (Adey, Nagey, Robertson, Serret, & Wadsworth, 2003; Adey, Robertson, & Venville, 2001, 2002; Adey, Shayer, & Yates, 2001) or Thinking Science, i.e., TS, programme, developed originally in the mid-1980's in the UK stands up as one which goes beyond seeking to have children merely 'know more'. In Ireland, a body of research is underway to

Table 1: Previous / current research in Ireland in cognitive acceleration in science education

Researcher	Institution	Focus
Maume (1998)	TCD	CASE 11-14 in Transition year only
Gallagher (2008)	DCU	LTEY Infants (4 – 5 years) in the three schemata of classification, seriation, and causality
McCormack (2009)	DCU	CASE 11-14 across 1' – 2' transition
Ryan (2014)	DCU	CASE 11-14 – metacognition in the primary school
McCloughlin (1997 – date)	DCU	adapting existing lessons to the CASE "pillars" at three levels (secondary, and from 2000 primary and tertiary)(Gash, McCloughlin, & O'Reilly, 2008; T. McCloughlin, Gash, & O'Reilly, 2008; T. McCloughlin, O'Reilly, & Gash, 2009)

Maume (1998) and McCormack (2009) examined the feasibility of transferring the CASE 11-14 programme to the Irish context, and the results were very promising. Gallagher (2008) and Ryan (2014) on the other hand examined contrasting aspects of the cognitive acceleration / thinking skills programme in primary school specifically . Gallagher (Gallagher) looked at specific schemata for 4-5 year olds, and Ryan (Ryan) looked at specific pillars such as metacognition, all the more impressive as metacognition was seen as a difficult entity to investigate.

DISCUSSION

If stakeholders assert, and many do, that primary teachers should know the basics, fundamentals or primitives of science in order to teach science to children, leaving aside a definition of 'knowing', then the same stakeholders need to qualify their assertion by a definition of 'knowing' and a quantification of what is known. There is a reluctance to do this, and even where a broad scope of objectives are intended for children to learn science i.e., the 'curriculum', specially the 'revised' curriculum of 1999 (Assessment, 1999), there is little guidance in the matter of the two points of qualification of knowing and quantification of what is known. This leads to a number of fundamental "thoughtful questions" for teacher educators which will be briefly examined in turn.

Thoughtful question 1, how much should a primary teacher know?

As mentioned above, there is a lack of consensus as to how much a primary teacher should know. Of course, in order to answer the 'how much' question, one first needs to ask and answer the point as to what kind of knowledge and understandings should a teacher have? This will in turn depend on the stakeholders' views of what knowledge is and what learning is? One of the issues, the CASE project attempted to address was the issue of whether there is a central processing unit and how it might benefit an overarching view of intelligence. Notwithstanding the findings of researchers on multiple ‘intelligences’ (Kincheloe, 2004), the main argument appears to be no more than an attempt to explain how different people have different expertise or skills – preferable terms than ‘intelligences’ – and that the argument is political i.e., to assure the masses that everyone is valued for their own especial expertise and that everyone has a speciality of some sort. All this is very well, commendable even, but there is a lack in explaining how intelligence works from an epistemological viewpoint. No such lack exists with respect to the CASE project, furthermore, whereas ‘multiple intelligences’ can say little about the Flynn Effect; CASE researchers have noted an anti-Flynn effect (Shayer, Ginsburg, & Coe, 2007) over the last 30 years which counters the argument that CASE focuses on a simplistic view of intelligence or is merely a motivational exercise. It is much more, seeking to make explicit and apply Jean Piaget’s and Lev Vygotsky’s (Shayer, 2003) observations and theories of learning which are summed up in the Five Pillars of CASE, Table 2., in effect, methodologies to learning – not facts – but ‘ways of thinking’. ‘Ways of thinking’ are the *schèmes* of Jean Piaget (Piaget, 1928). Piaget defined a *schème* as the mental representation of an associated set of perceptions, ideas, and/or actions. Piaget considered *schèmes* to be the basic building blocks of thinking, which could be ‘discrete and specific’, or ‘sequential and elaborate’. Finally, certain *schèmes* were considered age-appropriate developing when a state of ‘readiness’ had been achieved, and Piaget suggested a model of stages which could be indicative of such a state of ‘readiness’. ‘Readiness’ is, of course, a key concept in literacy and numeracy.

Table 2: The Five Pillars of CASE: an Cúig philéar de CASE

Pillar *Piléar*	Essence
Cognitive conflict *Coimhlint chognaíoch*	thinking about a problem in a way that challenges prior knowledge
Social Construction *Tógála sóisialta*	sharing explanations and under-standings of a problem and potential solutions.
Bridging *Droicheadú*	working together to apply ideas ‘generated’ in the lesson to problems in the real world
Concrete preparation *Ullmhú coincréiteach*	introducing a problem and helping with any new vocabulary or ways of doing
Metacognition *Meiteachognaíocht*	reflecting on thinking and articulating approaches to solving the problem

In addition to a teacher having proficiency in the five pillars or methodologies of CASE, the specific content of a teacher education course would focus on the *schèmes* and content would be channelised to meet goals that involved proficiency in each *schème*, Table 3.The assessment of such a programme would not be in content acquisition but rather in direct measurement of cognitive level which is a function of integration of *schèmes.*

Table 3: *Schèmes* and their essence

Schème	Essence
Classification	Categorising objects or an array according to sensory similarities or dissimilarities
Seriation	Linear classification
Time sequencing	Linear classification in time
Causality	Understanding "cause and effect"
Conservation	Understanding that the number, weight or volume of physical entities remains constant despite changes in physical arrangement
Proportionality	Understanding the likelihood or chance of an event happening
Correlation	Understanding possible relationships between two or more variables
Combinatorial thinking	Understanding possible combinations of objects yields a new result
Equilibrium	Understanding that changing two or more variables until they balance
Control of variables	Understanding that changing one variable affects another

Assessment of student teachers in terms of their cognitive level raises a second question, namely:

Thoughtful question 2, would you expect a 5th class child to have a higher cognitive level than an undergraduate student teacher?

It would be expected that the answer to this would be in the affirmative, but the reality is not so simple. In a typical set of 3 samples, Figure 2., 5th class boys and 3rd year – final year - Bachelor of Education students completed assessments of cognitive level SRT II Volume and Heaviness - range 1-3A based on Piaget's "child's construction of quantities"(Piaget & Inhelder, 1974). My initial hypothesis was that the undergraduates would be bunched up around the scores of 7 – 8, and certainly there would be no overlap, however this is in fact not the case. I also tested 2nd year Junior Certificate level students in secondary school – SRT III Pendulum - range 2B - 3B based on Piaget's "the growth of logical thinking" (Inhelder & Piaget, 1958) – and it was noteworthy that no student achieved the 3B score. These results are consistent with the findings of Shayer et al. (2007). This is somewhat disturbing as, cognitively speaking, graduates from the Bachelor of Education programme who are scoring much lower in cognitive scales than 5th class boys or even secondary school students will inevitably lead to lessons devised as too simple for the boys leading to disenchantment in education. Whereas the *schèmes* outlined in Table 3. begin at specific ages in children; it is often assumed that they should be only addressed at that age. This is in fact a fallacy, as all the *schèmes* benefit from 'enrichment' through further development from work designed to promote a particular *schème* throughout life.

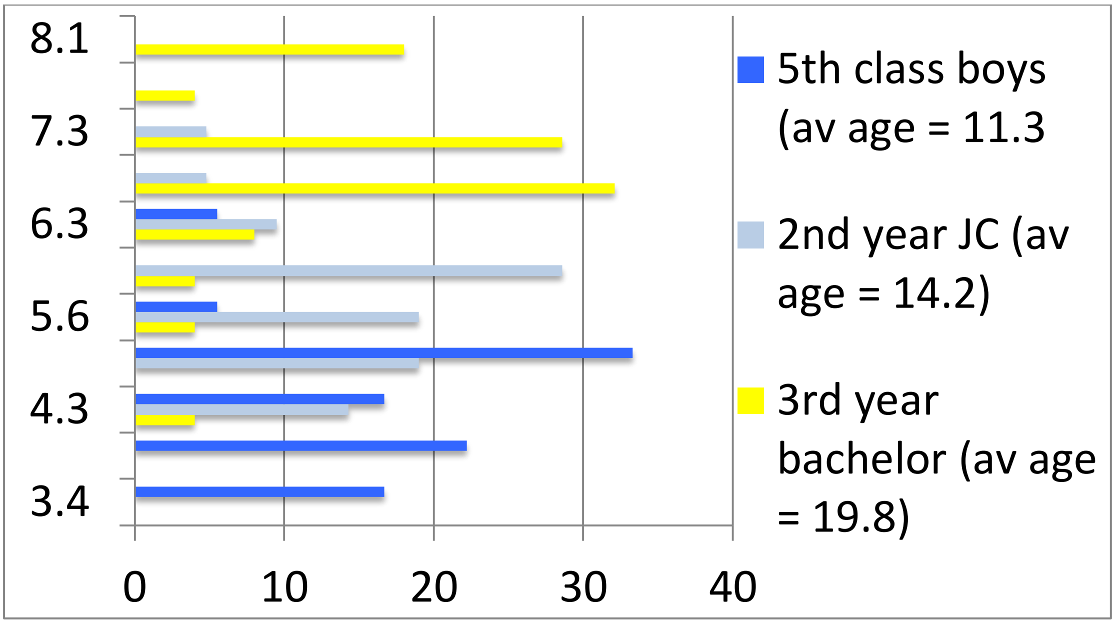

Figure 2: Piagetian Levels in three typical samples

Finally, in one approach final year Bachelor of Education Students on an elective course, n=74, did show a general (proportion of students achieving 3A or 3B) 'improvement' of cognitive level after 'engaging' with CASE, in effect a remediation of the downward shift below 6.5. This approach involved:

- Experiencing 36 hours of CASE 11-14 lessons, plus reflections, and
- teaching 3 CASE lessons, plus evaluations, on teaching practice, and
- writing and researching an essay on the CASE methodology (T. J. J. McCloughlin, forthcoming).

Thus, it can be said that these students were best prepared to teach science in way that does not focus on content without context or doing hands-on practical sessions without a thinking or 'minds-on' component.

CONCLUSIONS

- Student teachers have too great a spread of cognitive levels, including alarmingly low cognitive levels, given their educational background.

- It is recognised that some student teachers have a deficit in content and/or skills. However, science methods courses do not often seek to remediate knowledge deficits or skills deficits in science – they usually try to provide 'experiences' for students to become 'confident' in science in order to develop science pedagogy. But, science content and skills deficits can be addressed by engaging in a CASE-informed ITT course.
- The general principle of 'improvement' or 'acceleration' (a higher level sooner) is mediated through a different way of teaching (invoking the 5 pillars: concrete preparation, social construction, bridging, metacognition, cognitive conflict) rather than just teaching / transmitting more content ("the one big thing").

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A Smartphone-based Student Response System for Obtaining High Quality Real-time Feedback – Evaluated in an Engineering Mathematics Classroom

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The many pedagogical benefits and educational uses of student response systems (SRS) are well documented (Caldwell, 2007). These include improved student learning, increased student interaction and increased student satisfaction, to list but a few. However, while several different types of SRS exist, they currently have limited input capabilities. Most devices do not allow for a generic freeform input, such as mathematical equations, graphical methods or circuit diagrams. This lack of freeform input is of key concern in the Engineering, Science and Mathematics disciplines where such information is fundamental to the student learning experience. For example, consider the minimisation of a Boolean function using a Karnaugh Map or the design of an electrical circuit to meet a predefined requirement or a mathematical analysis of a problem. It is important that students can carry out these fundamental processes and, if we are to capture immediate feedback of the students' grasp of such methodology, then it is necessary for a SRS to facilitate freeform input. In this paper we evaluate a system that uses student-owned smart phones and tablets, along with the appropriate applications, as a 'smart device' student response system (McLoone *et al*, 2013). This system allows for freeform response and also offers a more practical and portable solution in comparison with existing solutions. In brief, the system consists of three key components, namely a student application that allows for freeform input (through sketching capabilities), a lecturer 'review and feedback' application and a cloudbased service for co-ordinating between these two applications. This paper presents a brief overview of the smart phone-based SRS and evaluates its potential benefits in a classroom context, namely a first year Engineering Mathematics class in DCU. Initial feedback from both the lecturer and the students is very positive. Details of the actual Mathematics module, the evaluation process and the feedback obtained are presented within.

INTRODUCTION

Student response systems exist in the educational literature under many different guises (Fies and Marshall, 2006), including audience response systems (Miller *et al*, 2003), classroom response systems (Roschelle *et al*, 2004), voting machines (Reay *et al*, 2005) and clickers (Barber and Njus, 2007). These systems are all very similar in nature, consisting of a transmitter device for the students to communicate their responses, a receiver device for the lecturer to collate this information and software that presents the responses in a convenient form. The research literature clearly illustrates the many pedagogical benefits of student response systems including improved student learning, increased student interaction, increased student preparation for classes, increased student attendance, increased student satisfaction and the creation of an enjoyable learning atmosphere (Barber and Njus, 2007; Caldwell, 2007; Moredich and Moore, 2007; Auras and Bix, 2007; Skiba, 2006). In addition, SRSs can be used for student assessment (Caldwell, 2007) and for obtaining anonymous student feedback (Graham *et al*, 2007).

Unfortunately, most of these devices only allow for a multiple-choice input, whereby students select from a set of possible answers to a given question. Some devices do allow for a numerical or texual- based submission. However, none of these devices cater for a more generic freeform input, such as a mathematical equation, a circuit diagram or a graphical method. This lack of freeform input is of key concern in the Engineering and Science disciplines where such information is fundamental to the student learning experience. Consider, for example, the scenario whereby a student is required to carry out a mathematical analysis of a problem. While it is nice to get the correct answer, it is ultimately the process of analysis itself that provides the real insight to the student learning. It is very important that students can carry out such analytical processes and, if we are to obtain real-time feedback of the students' grasp of such knowledge, then is necessary for a SRS to facilitate freeform input.

McLoone *et al* (2013) have developed such a system for use on smart phones and/or tablets. The system consists of a student application that allows for freeform input (through sketching capabilities), a lecturer 'review and feedback' application and a cloud-based service for coordinating between these two applications. Figure 1 below gives an overview of the overall system and illustrates how it can be used.

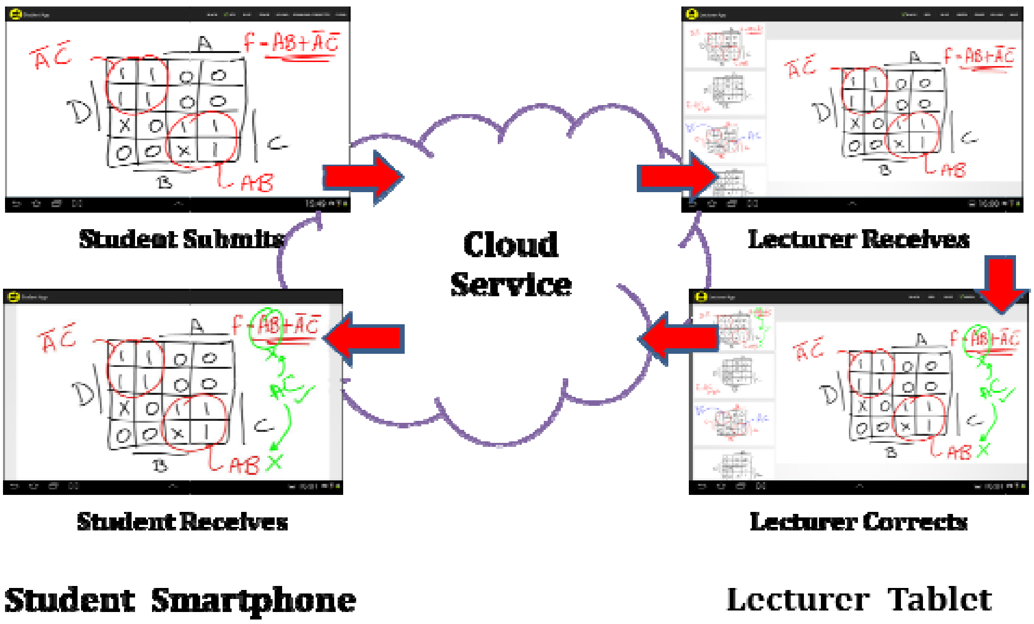

Figure 1: The Smartphone

Using the student application on their smartphone (or tablet) the student can sketch an answer to a posed question. This response can then be submitted anonymously in real-time to a shared database, which is currently stored on the Google App Engine cloud service. The lecturer can view all received anonymous responses (again, in real-time) and can select any of those responses for further analysis. The lecturer can also add edits to any of the responses and send this back to the students, if need be. It is this system that is evaluated in this paper. Currently, the system is only available for Android based smartphones and tablets.

The rest of the paper is structured as follows. The next section outlines the methodology used for evaluating the smartphone-based SRS. An overview of the educational situation is also provided. Results of the evaluation are presented and analysed in section 3. The paper ends with some conclusions and suggestions for future work.

METHODOLOGY AND EDUCATIONAL SITUATION

The smartphone-based SRS was evaluated in a first year Engineering Mathematics module in DCU. This 5 ECTS module is taken by all first year engineering students in DCU including students taking Electronic, Digital Media, Mechatronic, Information and Communications, Mechanical and Manufacturing and Biomedical Engineering. The module takes place in the second semester of first year and is the second mathematics module taken by these students. It has two key sections. The first six weeks of the module covers basic calculus (differentiation, integration, applications of integration and differentiation and an introduction to ordinary differential equations) while the second six weeks covers complex numbers and matrices. The SRS was evaluated during the first 6 weeks of the module.

There were 167 students registered for the module but attendance was relatively poor due to the availability of online notes and, in some instances, recorded lectures. Thus, the typical class size in attendance was approximately 70 students and comprised of about 10 female and 60 male students. Furthermore, there were 15 international and 3 mature students in attendance, on average.

The lecturer of the module (and co-author of this paper) has found that students tend to have a prescriptive understanding of topics in functions and calculus, i.e. they have a fixed rule-based knowledge which allows them to process certain problems in a structured fashion provided that they are similar to ones encountered before. It is therefore a challenge to augment this rote-learning with a more flexible ability to visualize and understand the key concepts. The purpose of using the SRS was to see whether the technology could be effective in gauging the students' ability in this regard. Hence, questions posed were simple and required little or no computation or manipulation of expressions but instead challenged the students' fundamental understanding. An additional aim was to investigate how effective it would be in maintaining students' interest during a two-hour lecture on Friday mornings.

Several questions were given to the students during the evaluation. An example of one such question involved assessing the students' understanding of the absolute value operation. Students were sent a depiction of the function $f(x) = \sin x$. They were then asked to add two more functions to this sketch to graphically represent $g(x) = |\sin x|$ and $h(x) = \sin |x|$. A sample set of student responses, as received on the lecturer's tablet is shown in figure 2, with one such response selected by the lecturer for post analysis and discussion.

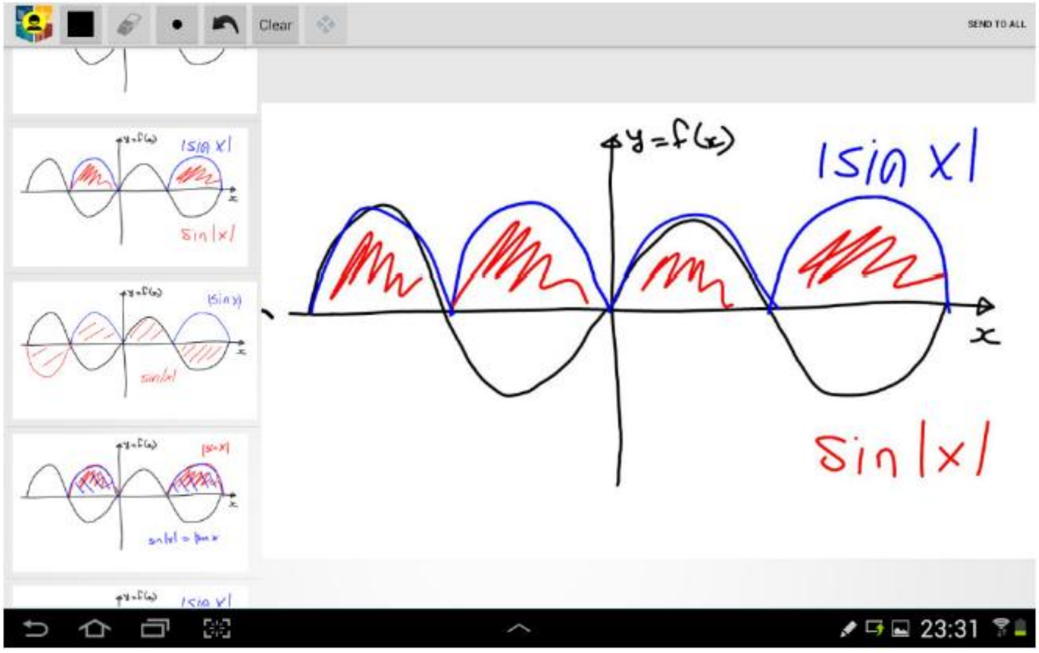

Figure 2: Sample sketch responses for the functions $g(x) = |\sin x|$ and $h(x) = \sin |x|$

Some students tend to assume that any function with an absolute value as part of it must produce positive output. This was evident in several of the responses received from the students. This question clearly challenges this particular misconception. On receipt of the student responses, the lecturer now has the opportunity of highlighting this misconception and can draw the students' attention to the issue at hand.

Several such questions were posed during a typical lecture session on two different occasions. At the end of the second occasion, students were presented with a survey seeking their feedback on the new smartphone-based SRS. The lecturer, who had no prior knowledge or experience of the SRS, was also asked for his feedback. Both the lecturer's and the students' feedback are presented and discussed in the next section.

RESULTS AND ANALYSIS

A quick poll indicated that about 40% to 50% of the attending class of students had access to Android based smartphones or tablets. Students who did not have a suitable device were teamed up with someone who did and so the exercises were all group-based. In total, 46 survey forms were completed and returned to the lecturer at the end of the evaluation sessions. The student feedback is summarised in table 1 below.

Table 1: Student feedback on smartphone-based SRS, where 1 to 5 represents strongly disagree, disagree, not sure, agree and strongly agree respectively.

Statement	**Average rating (1-5)**	**Std. dev.**
I found the app easy to use.	4.15	0.70
I felt the app was quick and responsive.	3.15	1.23
The app performed as expected.	3.33	1.03
The app provided a good way to interact in class.	4.35	0.79
The app provided a good way to give feedback/responses.	4.22	0.92
The flexibility of providing a sketch is really useful (in comparison to choosing either a, b, c or d for example).	4.22	0.99
The use of the response system makes my learning more enjoyable.	4.50	0.55
I was motivated to respond to the lecturer's questions using this system.	4.30	0.76
I would like to use this response system again.	4.30	0.76

Table 1 clearly shows that most students were strongly in favour of the smartphone based student response system and, in particular, felt that the flexibility of providing a sketch as an input option was really useful. Moreover, they felt that the system provided a good means of interacting in class. They were motivated to respond to the lecturer's questions and wanted to use the system in future classes. The feedback in table 1 also shows that there was a mixed feeling regarding the student application itself with a large number of students noting that the application was not quick and responsive and did not work as they expected. This issue was largely due to some inherent bugs in the current system, which is still very much a work in progress. These caused the application to crash or stop working quite often and proved quite frustrating, at times, to some of the students. Nevertheless, they still appreciated the value of the overall system.

From the additional feedback obtained, via comment boxes, several students noted that the SRS was a positive way of "*interacting between student and lecturer*." They "*liked the freedom of drawing*" their "*own answer*" and found the graphical input useful and felt that it allowed the lecturer to see if they really understood the material. As expected, most students appreciated the "*fact that all submissions were anonymous*" allowing them to provide responses without the fear of being identified and it also meant that they were "*less worried about the answer being wrong*." Finally, most students commented on how the system crashed quite often and would like to see this issue resolved for future use.

The lecturer of the module was extremely positive in his assessment of the technology, although it was not without its problems, as previously noted. Despite this, the lecturer noted that the sessions were keenly enjoyed by the class who responded very well to the different class-room dynamic and it certainly served its purpose of breaking up an otherwise passive 2-hour slot. The lecturer also indicated that he would like to use it more widely in his future lecturing.

In the opinion of the lecturer the technology highlights to students the central importance of a visual understanding of mathematics and the system's simple input capabilities, which at first may seem a drawback, actually became a positive in this regard. For example consider the case of sketching a function. The simple drawing scheme available means that students are forced away from their traditional approach of computing several input-output pairs and interpolating between them. Instead they must perform a simple free-hand sketch based on their intuitive understanding of the function's behaviour. The lecturer stresses to them that it is this intuitive understanding of a function's general behaviour that constitutes real mathematical knowledge, as opposed to manipulation of tabulated data. While students are resistant to this approach, allowing them to practice in a relaxed classroom atmosphere is one step towards developing this skill.

The lecturer also noted that, like any new learning technology, it is important to choose questions that are simple and clearly assess a small number of principles. Vaguely worded or overly complex scenarios do not translate well to this arena. In addition, it is important to encourage students to submit blank or empty solutions if they genuinely don't know the answer (given that the purpose of the exercise is to gauge the level of understanding of the class as a whole).

The majority of students engaged well and the sessions proved very worthwhile. However the anonymity provided by the SRS did produce a certain amount of obscene replies on one occasion when the lecturer had the system hooked up to the inclass screen, while replies were coming in. Although these can be brushed off and can actually serve to break tension and build rapport they can sometimes become intrusive and get out of hand. It is important to develop a smooth system for connecting the device to the projector and disconnecting as appropriate, something that came with experience of how the process flowed. The lecturer noted that the development of a simple software solution that could simplify this process, i.e. allowing responses to be hidden until desired, would be extremely beneficial. Interestingly, several of the students proposed similar suggestions in their feedback.

CONCLUSIONS

This paper has evaluated a recently developed smartphone-based student response system (McLoone *et al*, 2013) in a first year Engineering Mathematics class in DCU. Both the lecturer and the students found the concept of offering freeform input using sketches very beneficial for submitting and receiving real-time in-class responses that, in turn, provided valuable insight to the students' deep understanding of the mathematical content covered during the lecture. In addition, the system provided a good means of interaction within the classroom and helped break up what was otherwise a 2 hour long traditionally one-way lecture. The students, in particular, noted that the anonymity provided by the system allowed them to respond without fear of being identified and, therefore, of giving a wrong answer. On the other hand, the lecturer and, indeed, some of the students noted that such anonymity also resulted in some obscene submissions being received by the lecturer. This issue could potentially be resolved by not allowing students to see such submissions. In other words, the system can be used so that only the lecturer can view all student responses and, subsequently, can choose to share whichever response they seem suitable for further discussion. Moreover, the authors feel that this issue arises as a result of a slight immaturity among first year students entering college (and particularly among male students). It is hoped that this issue will be investigated in future evaluations of the SRS.

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Project Maths and PISA: Comparing the coverage of PISA mathematics items by the Project Maths and pre-Project Maths curricula

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Project Maths (PM) is a new activity-based post-primary mathematics curriculum. Implementation began in 2008 in 24 initial schools and has now extended to all post-primary schools in Ireland. The Irish sample for PISA 2012 included students in all of the Initial Project Maths (IPM) schools, as well as students in the regular PISA sample, most of whom had not studied the PM curriculum at all (NPM). This paper provides the background to a project that compares the performance of students at IPM and NPM schools on PISA 2012 mathematics scales and subscales, and builds a model of student performance that includes PM status. First, the paper sets out the background to Project Maths and the framework of PISA mathematics. Drawing on a test-curriculum rating process, it then notes similarities and differences between the PISA mathematics framework and both the PM and pre-PM curricula. Three mathematics experts rated the likely familiarity of students with the concept, the context, and the main process underlying PISA 2012 trend mathematics item. Across all syllabus levels, students studying the Project Maths curriculum were expected to be more familiar with the PISA items than students studying the pre-PM curriculum. The curriculum analysis was a precursor to analysis of the performance of students at IPM and NPM on overall PISA mathematics, on the four content scales (Change & Relationships, Space & Shape, Quantity, and Uncertainty & Data), and on the three process subscales (Formulating, Employing, and Interpreting). The responses of students in IPM and NPM schools are also compared on several measures of attitudes towards mathematics, including intrinsic motivation to learn mathematics, mathematics self-concept and mathematics anxiety. A multi-level model (school, student levels) examines the effects of a range of variables on overall PISA mathematics performance, including student gender, socio-economic status, attitudes towards mathematics, mathematics intentions, grade level, and school PM status. The purpose of the model is to gain a clearer insight into the range of school and student factors operating on performance in PISA mathematics, including the effects of studying under the PM curriculum (see www.erc.ie/pisa for the full report). The outcomes of the study will be discussed with reference to published research on the implementation of Project Maths in schools, and the actions that are needed to support teachers in implementing PM in schools.

INTRODUCTION

Project Maths is the new post-primary mathematics curriculum. It focuses on developing students' understanding of mathematical concepts and their mathematical skills using meaningful examples from everyday life (NCCA, 2011). Project Maths also aims to foster students' enthusiasm for mathematics and to encourage students to think creatively about the ways mathematics can be used and applied (Jeffes *et al.*, 2012). It is underpinned by Realistic Maths Education, a pedagogy which emphasises dialogue, exploring connections, and learning from experimentation and misunderstanding (Lubienski, 2011, NCCA, 2005). Both the Junior Certificate and Leaving Certificate PM curricula are divided into five strands:

Statistics & Probability, Geometry & Trigonometry, Number, Algebra, and Functions. Project Maths was introduced in 24 pilot schools in 2008 with full, national implementation to be completed by 2015.

The Programme for International Student Assessment (PISA) is an OECD study of the achievement of 15-year-olds in mathematics, reading, and science. The PISA 2012 mathematics framework defines mathematical literacy as:

> An individual's capacity to formulate, employ and interpret mathematics in a variety of contexts. It includes reasoning mathematically and using mathematics concepts, procedures, facts and tools to describe, explain and predict phenomena. It assists individuals to recognise the role that mathematics plays in the world and to make the well-founded judgments and decisions needed by constructive, engaged and reflective citizens (OECD, 2013a, p. 25).

For the purposes of assessment, the PISA 2012 definition of mathematical literacy is conceptualised in terms of three interrelated aspects:

- The mathematical content assessed in the areas of Change & Relationships, Space & Shape, Quantity, and Uncertainty & Data;
- The mathematical processes used by students in solving problems, categorised as *Formulating* situations mathematically; *Employing* mathematical concepts, facts, procedures, and reasoning; and *Interpreting*, applying, and evaluating mathematical outcomes; and
- The contexts in which mathematical problems are located, whether personal, occupational, societal, and scientific.

In addition to the assessments of mathematical literacy, PISA collects background information from questionnaires on students' family life, attitudes towards mathematics and education, learning behaviours, educational career, and ICT familiarity. Ireland has participated in PISA since the first cycle in 2000 and in PISA 2012, students in Ireland scored significantly above the OECD average on scales of mathematics, reading, and science (Perkins *et al.*, 2013).

In 2012 and in previous PISA cycles, however, students in Ireland scored below the OECD average on the Space & Shape mathematics subscale (Cosgrove *et al.*, 2005; Perkins *et al.*, 2010). Performance in PISA has been cited along with failure rates in Leaving Certificate mathematics among the factors which prompted the debate on reform of the mathematics curricula and the development of Project Maths (Conway & Sloane, 2005). PISA 2012 presented an opportunity to compare the achievements of students in Initial Project Maths (IPM) schools to those in Non-initial Project Maths schools (NPM) so the PISA sample included students in all of the IPM schools as part of the nationally representative sample. For the purposes of this paper, PISA mathematics can be conceptualised as an assessment tool to measure the impact of Project Maths as an intervention. The PISA mathematics test also provides a benchmark against which to compare the performance of students who have studied under the Project Maths curriculum and those who have studied under its predecessor.

As part of the implementation of Project Maths, the Department of Education and Skills commissioned an independent evaluation of the impact of Project Maths on student achievement, learning, and motivation (Jeffes *et al.*, 2012, 2013). The evaluation included a standardised assessment of student achievement, a survey of attitudes, analysis of students' work, and case studies in selected IPM and NPM schools. Students in Second and Third years of the Junior Cycle and in Fifth and Sixth years of the Senior Cycle took part. Overall, few differences were identified between the performance of IPM and NPM students, with IPM students in the Senior Cycle scoring better on Strand 2, Geometry & Trigonometry, for example. Likewise teachers' approaches appeared to be similar, at least as indicated by students' written work. In the survey of students, those in IPM schools did report more frequent use of certain of the new processes and activities associated with Project Maths: using real-life situations, making links between maths topics, working in small groups, and using computers (Jeffes *et al.*, 2013). However, this was often alongside more transmissive activities like reading from textbooks and copying from the board (Jeffes *et al.*, 2013). Other aspects of Project Maths were less successful and students reported discomfort with multiple interpretations, which is perhaps understandable since the students had been taught since Primary School to find the single right answer (Jeffes *et al.*, 2013). In conjunction with PISA, Cosgrove *et al.* (2012) surveyed teachers in IPM and NPM schools. Those in IPM reported positive changes in teaching and learning practices, though this was perhaps at the expense of teacher confidence in some areas of teaching and assessment.

Neither the old Junior Cert mathematics curriculum nor the new Project Maths curriculum is directly based on PISA processes and content areas, though it is instructive to note the extent to which each version of the curriculum corresponds to the PISA mathematics framework. As part of the Project Maths report, a PISA Test-Curriculum Rating Project (TCRP) was undertaken in 2014, building on a similar project following PISA 2003 when mathematics was last the major domain (Close, 2006). It aims to compare the coverage of PISA test items by the Project Maths curriculum and the previous curriculum.

METHOD

Three independent experts in second-level mathematics education undertook ratings of PISA 2015 trend items, reviewing a total of 40 units containing 71 items. The items were evenly distributed among the four PISA content subscales: Change & Relationships (23.9%), Space & Shape (23.9%), Quantity (26.8%), and Uncertainty & Data (25.4%). First, ratings were given on the process and content area or syllabus strand that best corresponded to each PISA item (Table 1). Next, the raters considered the expected familiarity of students under the Project Maths curriculum and the old curriculum with the concept, context, and process of each PISA item on a three-point scale of *Not familiar*, *Somewhat familiar*, and *Very familiar*, and gave separate ratings for students working towards taking a Higher, Ordinary, or Foundation Level Junior Certificate Maths exam. After they had undertaken independent ratings, the raters met to discuss items on which there was disagreement, as well as wider issues in the implementation of Project Maths. On the basis of the meeting, ratings for each item were finalised and the coverage of PISA items in the two versions of the curriculum was determined. There was also extended discussion of the performance of students in Ireland on the Space & Shape subscale.

Table 1: Processes, pre-PM content areas, and Project Maths syllabus strands used in the TCRP

Process	Pre-PM Content Area	PM Syllabus Strand
Recall	Sets	Statistics & probability
Implement procedures	Number systems	Geometry & trigonometry
Connect	Applied arithmetic & measure	Number
Reason mathematically	Algebra	Algebra
Solve problems	Statistics	Functions
	Geometry	
	Trigonometry	
	Functions & graphs	

CURRICULUM ANALYSIS RESULTS

Students studying the Project Maths curriculum were rated as being more familiar with the concepts, content, and processes the PISA underlying items at all syllabus levels than students studying the pre-PM curriculum (Table 2). Even on areas where students of the pre-PM curriculum were rated as *Very Familiar* on average, familiarity ratings were higher for the Project Maths curriculum. Higher level Project Maths students are expected to be at least *Somewhat familiar* with every item and *Very familiar* with more than 80% of them; by contrast, students studying the pre-PM curriculum at Higher level were expected to be *Very familiar* with fewer than 55% of items. For Foundation level students, 25.4% of items were judged to be unfamiliar under the Project Maths curriculum compared to more than half (60.6%) under the previous curriculum. For some items, students were expected to be familiar with the process or with the content area in the given context of the PISA item even if not with the details of the item itself.

Almost all of the items were deemed to be covered by both curricula, 91.5% by the pre-PM curriculum and 97.2% by Project Maths. The most common process underlying the PISA items was Implement procedures (36.6%), followed by Connect (26.8%). Just a few items drew on the skills of Recall (7%) or Solving problems (8.5%). More than a quarter of the PISA items were on Statistics and Probability (28.2%) and more than a third were on Number (38%, corresponding to Number systems and Applied arithmetic and measure in the pre-PM content areas). Just 8.5% of items were rated under Geometry & Trigonometry, suggesting that many of the PISA items on the Space & Shape subscale require knowledge of areas beyond Geometry and Trigonometry.

Table 2: Expected student familiarity ratings for 71 PISA items in the areas of concept, context and process, by Junior Cycle syllabus level for the Pre-PM and PM curricula

	Students Studying Pre-PM Curriculum			Students Studying PM Curriculum		
	Not familiar %	Somewhat familiar %	Very familiar %	Not familiar %	Somewhat familiar %	Very familiar %
Concept – Higher	12.7	32.7	54.9	0.0	18.3	81.7
Concept – Ordinary	19.7	46.5	33.8	7.0	25.4	67.6
Concept – Foundation	52.1	36.6	11.3	25.4	32.4	42.2
Context – Higher	18.3	47.9	33.8	0.0	15.5	84.5
Context – Ordinary	36.6	43.7	19.7	2.8	19.7	77.5
Context – Foundation	59.1	28.2	12.7	8.4	25.4	66.2
Process – Higher	7.1	38.0	54.9	0.0	4.2	95.8
Process – Ordinary	22.5	45.1	32.4	1.4	28.2	70.4
Process – Foundation	60.6	23.9	15.5	12.7	16.9	70.4

Several content areas that are not covered by the PISA items reviewed were also identified: equations, functions, sets, both formal and co-ordinate geometry, trigonometry, and property of number. On the other hand, applied arithmetic and measure and statistics were deemed to be over-represented in PISA. Overall, PISA was considered neither to encompass everything in mathematics nor everything in the Irish curriculum. PISA was also described by the expert raters as linear, with little ambiguity and few opportunities for alternative approaches or lateral reasoning.

Only a small number of the PISA items were deemed not to be covered by the Project Maths curriculum at any level, including items concerning 2-D or 3-D rotation of objects and dealing with links between information on a table and information on a map or chart. There were other examples where information in a narrative description could be used to determine the correct formula to apply in answering the question; students in Ireland are likely to be familiar with the use of the formula but not with the narrative description. Project Maths was considered to have minimal coverage of data tables and the skills associated with interpreting tables.

Raters repeatedly pointed to the literacy demands of PISA items, with the implication that a high level of basic literacy is required to successfully attempt the items. The old curriculum was less reliant on written text than Project Maths and only information and data that were directly relevant to answering the question were provided. No information could be shown on a diagram that was not in the written description. On the other hand, Project Maths is more like PISA in its presentation of information.

The extent to which students might be able to apply skills learned in other subjects to PISA was also considered. Items involving maps and charts might be easier for students who had covered similar material in geography, for example, and students of technical graphics are likely to have a major advantage on PISA Shape & Space items. Similarly, subjects like woodwork, metalwork, and construction studies develop skills that are useful in Space & Shape. However, there are other subjects whose lessons can be applied to PISA items, such as business studies and science and the overlap between mathematics and other subjects was considered bi-directional.

CONCLUSIONS

Overall, the analysis presented here indicates that Project Maths at Junior Cycle level is closer in its conceptualisation to PISA mathematics literacy than the previous curriculum, suggesting that students in IPM schools might be better equipped for the PISA test. Project Maths, then, does show the potential to address some of the long-standing issues in the teaching and learning of mathematics in Ireland, such as teaching by transmission, and moving towards RME.

With respect to the OECD average score and comparison to other countries, concerns had been raised over Ireland's relatively poor performance on Space & Shape, which was significantly below the OECD average in both 2003 and 2012 (Perkins *et al.*, 2013). The same issue was identified across a number of English-speaking countries (OECD, 2013b), and points related to the teaching of geometry and trigonometry were also raised. The curriculum ratings indicate that the Project Maths curriculum may go some way to addressing the historic problem with PISA Space & Shape; the expert raters identified spatial relations and rotational geometry as examples of areas that are likely to improve under Project Maths. However, the complexity of PISA items also means that students are challenged to cross the boundaries between content areas and processes and to think creatively.

The research evidence (Jeffes *et al.*, 2012, 2013; Cosgrove *et al.*, 2012) suggests that teachers have been slow to move to the teaching and assessment style demanded under Project Maths, and this may be due in part to the anxiety caused by the implementation process that is still underway. Professional development workshops were discussed by the three experts in the context of the Shape & Space items but the issues are likely to affect other parts of the curriculum. An emphasis on practical pedagogy was apparent in the workshops with use of manipulables by teachers and of small-group discussion encouraged, for example. However, any of these approaches requires comfort on the part of teachers with using demonstration objects in class and with facilitating group discussion, neither of which can be taken for granted. Changes to how teachers approach mathematics require changes in teachers' and students' expectations of their roles.

For the full report on *Project Maths and PISA* and for further information on PISA 2012, see www.erc.ie/pisa

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Inquiry Based Learning in Primary Education: A Case Study using Mobile Digital Science Lab

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This paper presents a case study in Primary Education that promotes children's inquiry thinking skills in Physics through the mobile digital laboratory '*Labdisc Enviro'*. The case study has been implemented in an authentic primary school environment and the underlying context of the scenario has been based on Physics 'Ecosystems' unit. Our main target was to investigate effective educational techniques along with the different ways they can be used in order to promote inquiry based learning in primary school children. The proposed teaching approach is based on the model of Inquiry Based Learning (IBL), which seems to be one of the most efficacious approaches for promoting the development of critical thinking, active learning and in-depth information processing by students (Hi et al., 2008; Minner et al., 2010). The use of the mobile digital laboratory '*Labdisc Enviro*' gave added value to our case study because '*Labdisc Enviro'* incorporates sensors that can replace traditional pieces of laboratories' equipment by converting a simple class into a digital science lab. In this way, students get engaged into hands-on lab activities, which make the learning process more effective, appealing and enjoyable (Globisens Net, 2012). Another target of our approach was to apply a combination of various modern techniques for ensuring an in depth (quantitatively and qualitatively) assessment of the students' performance. Finally, the paper includes the evaluation findings of a pilot study carried out so as to scrutinize the degree of acceptability, effectiveness and efficiency of this inquiry based learning approach.

Key words: Physics, Inquiry based learning, Labdisc, modern assessments techniques

INTRODUCTION

Research in the field of teaching science highlights as one of the underlying benefits of the laboratory the fact that it allows students to interact experimentally with materials and models, reinforcing the observation and comprehension of natural phenomena (Kind et al., 2011; Ding et al., 2011). In contemporary pedagogics / education, experiments are considered to be an integral part of the lesson as well as a dynamic tool which enriches and strengthens the learning process (Bond-Robinson, 2005).

Although experiential learning has proved more effective compared with teaching through virtual experiments, every today schools, are deprived of the equipment required to implement experiments . Equally significant with the technical infrastructure is the teaching approach that is chosen in order for the experiments to be put into practical use in everyday school life. In contemporary pedagogical theory and practice, Inquiry Based Learning has already been established as one of the most promising educational approaches as it promotes the development of critical thinking, active learning and an in-depth processing of information (Hu et al., 2008; Minner et al., 2010; Bolte et al., 2012).

Although in both Greek and international bibliography there has been a significant number of Inquiry Based Learning scenarios for teaching science in all levels of education, their main weakness lies in the fact that they do not include assessment methodologies and tools. For the teacher, assessing students' performance in Inquiry Based Learning scenarios is a particularly difficult and challenging venture, as they will have to take into consideration, record and evaluate a variety of parameters (Darling-Hammond & Adamson, 2010).

Responding to this challenge, this paper has a dual purpose: a) on the one hand, to thoroughly present the design, development and application stages of an authentic Inquiry Based Learning scenario that makes the best of the science data logger Labdisc, b) on the other hand, to facilitate the teacher to evaluate, as accurately and fully as possible, both the individual and team performance of students through the combination of contemporary assessment techniques.

In this paper the teaching scenario which was developed and applied as well as the students' performance assessment techniques are presented. The paper concludes with a summary of our future aims.

NEW TECHNOLOGIES AND LABDISC

Many researchers support that the use of new technologies in science education enhances students' performance (Cepni et al., 2006). However, there is a lack of a methodological approach and the main question still remains. For the educational community, instructional design using technology is a challenge and a teacher needs to be very careful in the creation of his/her teaching scenario that will incorporate new technologies in order to improve the underlying educational process. In many implementations of inquiry instruction, the use of data logging and sensors is an integral part of the student's engagement in inquiry learning.

The Labdisc is an interdisciplinary "digital lab" with application across the field of Natural Sciences. It incorporates sensors that can replace traditional pieces of equipment by converting each class into a science lab. This solves the problem of inadequately equipped school laboratories, while minimizing the time needed to prepare a science course. Finally, the compatibility with state-of-the-art technological tools that have infiltrated the schools, such as interactive whiteboards and tablets, enables students to further exploit the data of their measurements.

THE LEARNING SCENARIO

The meaning of ecosystem is familiar to primary school students and especially to those in the sixth grade. Students, however, are not familiar with the components it consists of. Furthermore student are likely to misunderstand the meaning and the difference between temperature and humidity and the different use they represent.

Educational Objectives

Students acquire knowledge regarding:

- recognize the main ecosystems,
- to find their differences,

- to discern the factors that constitute an ecosystem.

Students cultivate skills and abilities like:

- to verify experimentally if the temperature varies from one ecosystem to another,
- to determine differences in temperature and humidity at different times of the same ecosystem,
- to record temperature and humidity using ‘Labdiscs’,
- to verify experimentally the difference in temperature and humidity between
- ecosystems.

Students form attitudes about:

- to develop a positive attitude towards the use of scientific methodology
- export of valid results.

Inquiry Learning Method

The existence of students' primary ideas concerning the ecosystems has led us to the selection of an "evolving research teaching model " of Schmidkunz & Lindemann (1992) which has been adopted in the curricula of several primary schools (e.g. in Greece and Cyprus) (Sotiriou et al. 2010). The particular model includes four stages of teaching: (i) Introduction - Stimulus – Hypothesis Formulation, (ii) Experimental approach of the task, (iii) Inference, (iv) Consolidation – Generalisation.

The underlying teaching scenario consists of four distinct steps, the implementation of which was completed within 6 teaching hours. Below are the details of the development and implementation steps of the scenario, as well as the combination of assessment techniques (e.g. testing, evaluation rubrics, peer-assessment, portfolios, etc.) that were used by the teacher to assess both the individual and team performance of students.

First Step. Introduction - Stimulus – Hypothesis Formulation

Introduction (Duration: 5 minutes)

Students start by watching introductory videos which show different types of ecosystems. Then, an initial discussion between the students and the teacher takes place in order for the latter to test their knowledge on ecosystems and remind them their names.

Hypotheses (Duration: 15 minutes)

After that, students work in groups of three or four formulating research hypotheses regarding: (i) the temperature that the school’s ecosystem will have, the marine ecosystem and the mountainous ecosystem. Hypotheses are made at three different times - during the morning attendance of students, in the middle of the school day and during afternoon hours. Students have to record all their hypotheses on a worksheet which has been created and edited by the teacher.

Second Step. Addressing the problem experimentally

Experimenting (Duration: 1 hour and 45 minutes)

Students conduct experiments in groups to test their hypotheses.

Experiment – students use Labdiscs to measure the temperature and humidity in selected ecosystems in the morning attendance.

After their arrival, students are divided in groups. Each group uses the Labdiscs to measure the temperature and humidity in the centre of the schoolyard taking rates concerning the school ecosystem. Then, they are taken to a nearby seashore where they also measure the temperature and humidity of the water. Due to technical difficulties, sea measurements are made at a very small depth. Finally, they are driven to the mountainous ecosystem where they make measurements of temperature and humidity respectively.

The same measurements are also made at noon which is considered the middle of the school day and at 2 in the afternoon before they leave school.

Measurements (Duration: 45 minutes)

In the next activity, the results of the measurements are discussed so that the changes in measurements in each ecosystem at different times during the day are put forth. For this reason, each group is given an evaluation sheet with a semi-structured conceptual map where students are asked to fill in keywords. The objective of this assessment is to enable students to match their measurements to those ecosystems, understanding their different characteristics.

Third Step. Drawing conclusions
Conclusions (30 minutes)

Groups summarise their recordings through classroom discussion, reach their final conclusions and record them on the worksheet. These relate to: (i) the diversification of the temperature and humidity rates between ecosystems, (ii) the diversification at the different times of the measurements.

Feedback (Duration 15 minutes)

Then, the teams return to their initial hypotheses that were made at the first stage with the help of the teacher and they check - correct - fill in where needed. (Duration: 45 minutes)

Fourth Step. Consolidation - Generalisation
Everyday life connection (Duration: 10 minutes)

In this step, students are asked to connect their measurements to everyday life. Each group responds to short-answer questions (worksheet) plucked from everyday life concerning the variability of the temperature and humidity measurements.

Peer evaluation (Duration: 15 minutes)

Then, each group swaps worksheets with another group -which is randomly selected- and proceeds to the evaluation of responses, justifying only the wrong answers. After that, students go on to check peer-assessment through class discussion with the assistance of the teacher and its final finding is readjusted accordingly.

Rubric evaluation (Duration:10 minutes)

The assessment of the worksheet is achieved with the help of holistic rubric that evaluates the credibility and complement of answers. Students are provided with a clear guide for grading the worksheets depending on the importance of each criteria.

Then, the teacher discusses and specifies the right answers and the teams check their initial estimates. After the final correction, each team gives its final mark.

Evaluate individual performance (Duration: 10 minutes)

With the completion of the scenario, each student fills in, individually, a test with multiple choice questions, matching activities, right or wrong and short answers through which their individual performance is evaluated.

Additionally, the teacher assesses the portfolios with the teams' worksheets and gives them a mark. The worksheets are assessed according to: the accuracy of the measurements, the comprehensive overview of the worksheets, the inferences made, the argumentation-justification of answers.

Final Grading

Each student's final score results from the quota of each of the aforementioned performances (gradings). More specifically, it emerges from the following type:

Final Grade = + [Peer evaluation]

+ [Rubric evaluation]

+ [Individual test]

+ [final assessment portfolios]

CONCLUSIONS

In this paper, the design, development and pilot implementation of an authentic Inquiry Based Learning teaching scenario was presented that utilises the digital laboratory devices 'Labdisc Enviro' with 6th graders in their Physics course. The evaluation of the findings from the pilot implementation demonstrates that: (a) students responded very positively and with sheer enthusiasm towards utilizing Labdisc in their school, (b) utilising Labdisc in multiple Inquiry Based Learning activities greatly improved the process of restructuring the students' primary ideas and (c) the teacher, by implementing a combination of contemporary assessment techniques, evaluated with as much completeness as possible the students' individual and team performance. Our short term goal for the future is to design, develop and implement further teaching scenarios which will make the most of the added value of the digital laboratory Labdisc in all levels of schooling.

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The Role of Inquiry Activities in Physics Education at Lower Secondary School

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Temperature and Investigation of phase transition are the main topics for the physics curriculum at 7th grade of the lower secondary school. Within the national educational achievement standards for these topics, the following pupil`s competences are required: description of observed phenomenon, recording of temperature vs. time dependences, discovery of factors influenced on experiment results, realization and evaluation of observations, presentation of own experimental data. The inquiry activities are indicated as one of the possible ways how to help pupils to obtain such competences. The role of inquiry activities at lower secondary school is discussed and explained by examples of computer based measurements in the topic Heat and Investigation of phase transition. For each activity the competences are defined, with focus on core elements of inquiry. The authors present first experiences with tools for formative assessment of inquiry activities.

INTRODUCTION

Information society brings new challenges for implementation of changes in the educational system. Instantaneous availability of information decreases the importance of memorising, however, at the same time it requires improving of skills needed for searching, understanding, processing and interpreting the findings. We have to make sure that all stages of education are interconnected in order to ensure effective acquiring of these skills and choosing the right tools. All our activities aim at developing certain parts of Science literacy of primary school students in Physics. Our determination stems from the desire to catch our students' interest in science and to lay a foundation stone of their scientific literacy that could be developed during their subsequent studies at a secondary school. One of the options seems to be applying inquiry activities in computer based laboratory.

PRIMARY SCHOOL PHYSICS AT SLOVAKIA

The content of Science curriculum is defined by the State Educational Programme according to ISCED 2. It specifies content standard and educational objectives for each theme. Physics (along with Biology and Chemistry) is part of a subject group called Man and Nature. The emphasis is on a constructivist approach, active learning, solving problems, group work, and creating a positive attitude towards science. Each school creates its own School Educational Programme, which enables the school to identify its own specialization.

Since our primary school puts special emphasis on foreign languages, Physics is taught for a recommended minimum of 4 years, 198 hours altogether. The topic that we chose is called Heat and Investigation of phase transition and is part of 7th grade Physics curriculum. Physics is taught 1 lesson a week in a class of about 25 students. Currently we are engaged in the national project Workshop whose aim is to equip Physics classrooms with modern educational tools such as interactive whiteboard, computers for students, and measurement systems with sensors. This way we can create even better environment for inquiry activities and make use of computers and measurement systems.

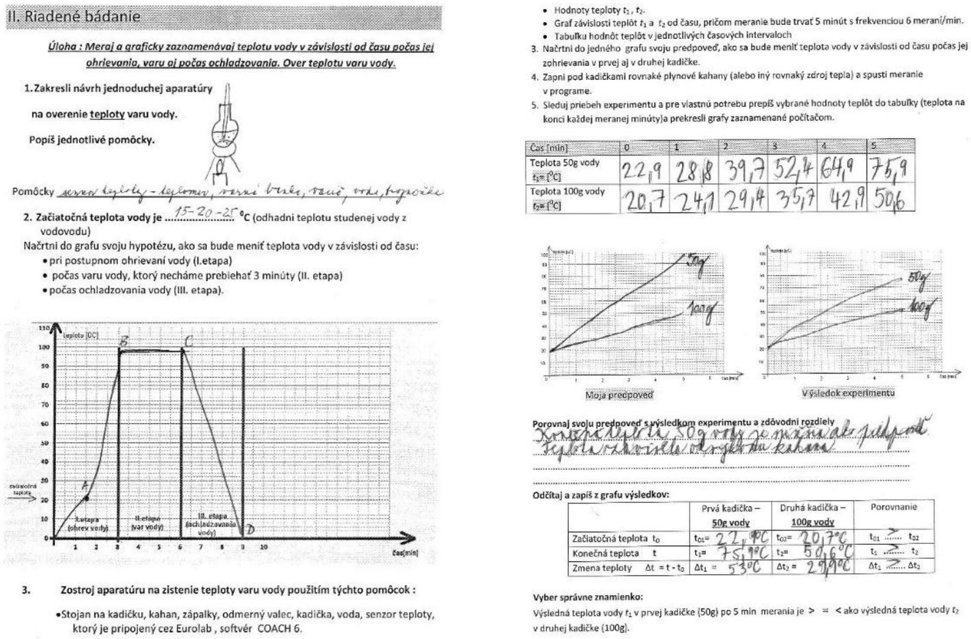
OUR SELECTION OF INQUIRY SKILLS FOR INQUIRY ACTIVITIES

During the performing of selected activities that are conducted as guided inquiry process we try to develop some basic scientific skills in the 7th graders, such as observing, realizing and describing of experiments. During the activities Boiling of a liquid, How heat is measured the students acquire the following skills:

1. **Defining a problem**. Students think about their task and its importance and analyse the key physical quantities.
2. **Stating a hypothesis**. Students propose an explanation based on what they already know about the problem and thus demonstrate their understanding of the fundamentals of the examined physical quantity.
3. **Measuring**. Students take measurements with a computer with the system CoachLabII, with sensors of temperature and with the help of software Coach 6. The above stated environment does not require any specific preparation, it is easy to operate. With regard to the skills it is crucial that students find out and realise how to scale a range of a temperature sensor and not to exceed it.
4. **Data evaluation**. Students compare their graphic prognosis with the real results and explain their findings orally. It is important to interpret a graph and the relationship between the temperature and time.
5. **Peer discussion**. Pair work is more suitable for those students who are not familiar with inquiry activities or measure temperature for the first time because it increases students` self-confidence. Once the students gain confidence, it is possible to measure temperature individually.
6. **Implementation of the knowledge**. Assembling of the devise enables our students to develop manual dexterity needed in everyday life. During the measuring of the temperature our students found out that different sources of warmth (spirit burner, gas burner, stove) reach a different temperature at a different time. Constructivist approach helps us to explain the meaning of power as the rate at which work is performed or energy is converted.

INQUIRY ACTIVITIES AT LOWER SECONDARY SCHOOL PHYSICS

Inquiry activities were tested on a sample of the 7th graders aged 13-14. Within the topic Investigation of phase transition we tested activities *Boiling of a liquid, measuring of the boiling point of water* and from the topic Heat we tested the activity *How the bodies warm up.* Both above mentioned activities were conducted with a group of 12 students who worked in 6 pairs as guided inquiry activities. Each pair received a worksheet and completed all tasks with an occasional teacher`s help. Each of the activities lasted for 2 forty-five minute lessons.



II. Riadené bádanie

Úloha : Meraj a graficky zaznamenávaj teplotu vody v závislosti od času počas jej ohrievania, varu aj počas ochladzovania. Over teplotu varu vody.

1. Zakresli návrh jednoduchej aparatúry na overenie teploty varu vody. Popíš jednotlivé pomôcky.

Pomôcky

2. Začiatočná teplota vody je 15-20-25 °C (odhadni teplotu studenej vody z vodovodu)

Načrtni do grafu svoju hypotézu, ako sa bude meniť teplota vody v závislosti od času:

- pri postupnom ohrievaní vody (I.etapa)
- počas varu vody, ktorý necháme prebiehať 3 minúty (II. etapa)
- počas ochladzovania vody (III. etapa).

3. Zostroj aparatúru na zistenie teploty varu vody použitím týchto pomôcok :

- Stojan na kadičku, kahan, zápalky, odmerný valec, kadička, voda, senzor teploty, ktorý je pripojený cez Eurolab , softvér COACH 6.

- Hodnoty teploty t_1 , t_2.
- Graf závislosti teplôt t_1 a t_2 od času, pričom meranie bude trvať 5 minút s frekvenciou 6 meraní/min.
- Tabuľku hodnôt teplôt v jednotlivých časových intervaloch

3. Načrtni do jedného grafu svoju predpoveď, ako sa bude meniť teplota vody v závislosti od času počas jej zohrievania v prvej aj v druhej kadičke.
4. Zapni pod kadičkami rovnaké plynové kahany (alebo iný rovnaký zdroj tepla) a spusti meranie v programe.
5. Sleduj priebeh experimentu a pre vlastnú potrebu prepíš vybrané hodnoty teplôt do tabuľky (teplota na konci každej meranej minúty)a prekresli grafy zaznamenané počítačom.

Čas [min]	0	1	2	3	4	5
Teplota 50g vody t_1= [°C]	22,9	28,8	39,7	52,4	64,9	75,9
Teplota 100g vody t_2= [°C]	20,7	24,1	29,4	35,7	42,9	50,6

Porovnaj svoju predpoveď s výsledkom experimentu a zdôvodni rozdiely

Odčítaj a zapíš z grafu výsledkov:

	Prvá kadička – 50g vody	Druhá kadička – 100g vody	Porovnanie
Začiatočná teplota t_0	t_{01}= 22,9°C	t_{02}= 20,7°C	t_{01} > t_{02}
Konečná teplota t	t_1= 75,9°C	t_2= 50,6°C	t_1 > t_2
Zmena teploty $\Delta t = t - t_0$	Δt_1 = 53°C	Δt_2 = 29,9°C	Δt_1 > Δt_2

Vyber správne znamienko:

Výsledná teplota vody t_1 v prvej kadičke (50g) po 5 min merania je > = < ako výsledná teplota vody t_2 v druhej kadičke (100g).

Figure 1: Students` worksheet for guided inquiry activity

Student`s worksheet contains: instructions, list of tools, and method. Before each practical activity students marked their graphic prognosis onto their worksheets. Students set all the required parameters in software COACH 6 – temperature, table with data, graph showing the relationship between temperature and time. After launching the experiment they were watching the results of measurement on the monitor. Then they compared their prognosis with results of the experiment and interpreted the graph showing the relationship between the temperature and time by completing the activities in the worksheet.

Figure 2: Guided inquiry activity during physics lesson at lower secondary school

HOW TO ASSES INQUIRY ACTIVITIES

During designing these inquiry activities it is important to think about assessment tools. Since students are subjected to a guided inquiry activity where the stages of the lesson are assigned we propose to assess the task with the graph in activity *Boiling of a liquid, measuring of the boiling point:*

Predicting a graph showing the relationship between temperature and time in which we can evaluate four possible statements:

- the beginning of the graph – at what temperature students began to draw their prognosis, that is the initial temperature of water
- graph curve at the boiling point, the constant temperature
- slope showing the heating up and cooling down of water, when both phases take the same amount of time, we expect the slower cooling down to be marked,
- the end of graph – the prognosis of the final temperature of water,

Interpretation of graphic results of the experiment in the given tasks – reading the graph, noting down the temperatures, changes of the temperatures, identifying of individual parts of the graph – warming up, boiling point, cooling down of water.

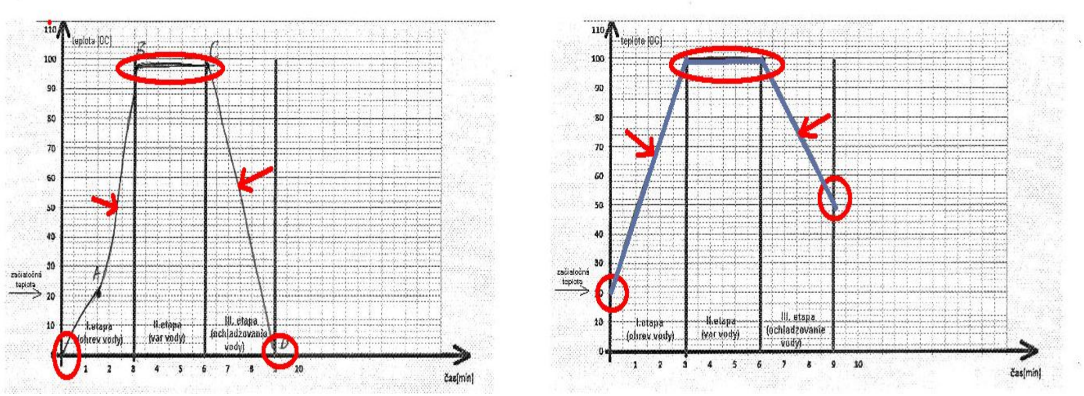


Figure 3: Temperature vs time graph, the typical students` prediction and final results

BENEFITS FROM INQUIRY ACTIVITIES FOR PUPILS AND TEACHERS

Inquiry activities with the help of a computer in teaching Physics at a primary school brought students these advantages:

- braking down Physics fundamentals into playful activities,
- developing manual dexterity,
- interconnecting a Physics experiment with digital technologies that are suitable for the tested age group ,
- increasing motivation to discover different natural phenomena,
- creating a positive attitude towards Physics.

Unfortunately, preparing these inquiry activities involves completing a considerable amount of time-consuming tasks for the teacher. He has to consider a suitable content and outcome of the activity as well as prepare some worksheets, tools needed for the experiment and evaluate students` work at the end. Other difficulties that have to be dealt with include classroom management, explaining different methods and introducing essential health and safety requirements. However, teacher can also gain a lot from running the experiment. Teacher takes the role of a guide who asks questions, observes students, leads discussions, and pays individual attention. Once students become familiar with the process of measuring temperatures and know how to work with software COACH 6, it is necessary to pick interesting content that will still motivate students.

CONCLUSION

Our goal was to perform a pilot test of guided inquiry in a laboratory equipped with a computer within chosen Physics topics in the 7th grade at a primary school. Students had a chance to conduct guided inquiry and measure with the help of a computer for the very first time. This experiment was a valuable experience for the teacher who put the knowledge gained in Lifelong Learning Programme in IBSE into practice. The aim was to observe individual work and to prepare topics for implementation and evaluation of designed inquiry activities. Positive feedback received from our students as well as successful completing of the tasks are a reason for creating new activities and testing method IBSE in Physics at a primary school.

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Project Maths and PISA: Comparing the coverage of PISA mathematics items by the Project Maths and pre-Project Maths curricula

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Project Maths (PM) is a new activity-based post-primary mathematics curriculum. Implementation began in 2008 in 24 initial schools and has now extended to all post-primary schools in Ireland. The Irish sample for PISA 2012 included students in all of the Initial Project Maths (IPM) schools, as well as students in the regular PISA sample, most of whom had not studied the PM curriculum at all (NPM). This paper provides the background to a project that compares the performance of students at IPM and NPM schools on PISA 2012 mathematics scales and subscales, and builds a model of student performance that includes PM status. First, the paper sets out the background to Project Maths and the framework of PISA mathematics. Drawing on a test-curriculum rating process, it then notes similarities and differences between the PISA mathematics framework and both the PM and pre-PM curricula. Three mathematics experts rated the likely familiarity of students with the concept, the context, and the main process underlying PISA 2012 trend mathematics item. Across all syllabus levels, students studying the Project Maths curriculum were expected to be more familiar with the PISA items than students studying the pre-PM curriculum. The curriculum analysis was a precursor to analysis of the performance of students at IPM and NPM on overall PISA mathematics, on the four content scales (Change & Relationships, Space & Shape, Quantity, and Uncertainty & Data), and on the three process subscales (Formulating, Employing, and Interpreting). The responses of students in IPM and NPM schools are also compared on several measures of attitudes towards mathematics, including intrinsic motivation to learn mathematics, mathematics self-concept and mathematics anxiety. A multi-level model (school, student levels) examines the effects of a range of variables on overall PISA mathematics performance, including student gender, socio-economic status, attitudes towards mathematics, mathematics intentions, grade level, and school PM status. The purpose of the model is to gain a clearer insight into the range of school and student factors operating on performance in PISA mathematics, including the effects of studying under the PM curriculum (see www.erc.ie/pisa for the full report). The outcomes of the study will be discussed with reference to published research on the implementation of Project Maths in schools, and the actions that are needed to support teachers in implementing PM in schools.

INTRODUCTION

Project Maths is the new post-primary mathematics curriculum. It focuses on developing students' understanding of mathematical concepts and their mathematical skills using meaningful examples from everyday life (NCCA, 2011). Project Maths also aims to foster students' enthusiasm for mathematics and to encourage students to think creatively about the ways mathematics can be used and applied (Jeffes *et al.*, 2012). It is underpinned by Realistic Maths Education, a pedagogy which emphasises dialogue, exploring connections, and learning from experimentation and misunderstanding (Lubienski, 2011, NCCA, 2005). Both the Junior Certificate and Leaving Certificate PM curricula are divided into five strands:

Statistics & Probability, Geometry & Trigonometry, Number, Algebra, and Functions. Project Maths was introduced in 24 pilot schools in 2008 with full, national implementation to be completed by 2015.

The Programme for International Student Assessment (PISA) is an OECD study of the achievement of 15-year-olds in mathematics, reading, and science. The PISA 2012 mathematics framework defines mathematical literacy as:

> An individual's capacity to formulate, employ and interpret mathematics in a variety of contexts. It includes reasoning mathematically and using mathematics concepts, procedures, facts and tools to describe, explain and predict phenomena. It assists individuals to recognise the role that mathematics plays in the world and to make the well-founded judgments and decisions needed by constructive, engaged and reflective citizens (OECD, 2013a, p. 25).

For the purposes of assessment, the PISA 2012 definition of mathematical literacy is conceptualised in terms of three interrelated aspects:

- The mathematical content assessed in the areas of Change & Relationships, Space & Shape, Quantity, and Uncertainty & Data;
- The mathematical processes used by students in solving problems, categorised as *Formulating* situations mathematically; *Employing* mathematical concepts, facts, procedures, and reasoning; and *Interpreting*, applying, and evaluating mathematical outcomes; and
- The contexts in which mathematical problems are located, whether personal, occupational, societal, and scientific.

In addition to the assessments of mathematical literacy, PISA collects background information from questionnaires on students' family life, attitudes towards mathematics and education, learning behaviours, educational career, and ICT familiarity. Ireland has participated in PISA since the first cycle in 2000 and in PISA 2012, students in Ireland scored significantly above the OECD average on scales of mathematics, reading, and science (Perkins *et al.*, 2013).

In 2012 and in previous PISA cycles, however, students in Ireland scored below the OECD average on the Space & Shape mathematics subscale (Cosgrove *et al.*, 2005; Perkins *et al.*, 2010). Performance in PISA has been cited along with failure rates in Leaving Certificate mathematics among the factors which prompted the debate on reform of the mathematics curricula and the development of Project Maths (Conway & Sloane, 2005). PISA 2012 presented an opportunity to compare the achievements of students in Initial Project Maths (IPM) schools to those in Non-initial Project Maths schools (NPM) so the PISA sample included students in all of the IPM schools as part of the nationally representative sample. For the purposes of this paper, PISA mathematics can be conceptualised as an assessment tool to measure the impact of Project Maths as an intervention. The PISA mathematics test also provides a benchmark against which to compare the performance of students who have studied under the Project Maths curriculum and those who have studied under its predecessor.

As part of the implementation of Project Maths, the Department of Education and Skills commissioned an independent evaluation of the impact of Project Maths on student achievement, learning, and motivation (Jeffes *et al.*, 2012, 2013). The evaluation included a standardised assessment of student achievement, a survey of attitudes, analysis of students' work, and case studies in selected IPM and NPM schools. Students in Second and Third years of the Junior Cycle and in Fifth and Sixth years of the Senior Cycle took part. Overall, few differences were identified between the performance of IPM and NPM students, with IPM students in the Senior Cycle scoring better on Strand 2, Geometry & Trigonometry, for example. Likewise teachers' approaches appeared to be similar, at least as indicated by students' written work. In the survey of students, those in IPM schools did report more frequent use of certain of the new processes and activities associated with Project Maths: using real-life situations, making links between maths topics, working in small groups, and using computers (Jeffes *et al.*, 2013). However, this was often alongside more transmissive activities like reading from textbooks and copying from the board (Jeffes *et al.*, 2013). Other aspects of Project Maths were less successful and students reported discomfort with multiple interpretations, which is perhaps understandable since the students had been taught since Primary School to find the single right answer (Jeffes *et al.*, 2013). In conjunction with PISA, Cosgrove *et al.* (2012) surveyed teachers in IPM and NPM schools. Those in IPM reported positive changes in teaching and learning practices, though this was perhaps at the expense of teacher confidence in some areas of teaching and assessment.

Neither the old Junior Cert mathematics curriculum nor the new Project Maths curriculum is directly based on PISA processes and content areas, though it is instructive to note the extent to which each version of the curriculum corresponds to the PISA mathematics framework. As part of the Project Maths report, a PISA Test-Curriculum Rating Project (TCRP) was undertaken in 2014, building on a similar project following PISA 2003 when mathematics was last the major domain (Close, 2006). It aims to compare the coverage of PISA test items by the Project Maths curriculum and the previous curriculum.

METHOD

Three independent experts in second-level mathematics education undertook ratings of PISA 2015 trend items, reviewing a total of 40 units containing 71 items. The items were evenly distributed among the four PISA content subscales: Change & Relationships (23.9%), Space & Shape (23.9%), Quantity (26.8%), and Uncertainty & Data (25.4%). First, ratings were given on the process and content area or syllabus strand that best corresponded to each PISA item (Table 1). Next, the raters considered the expected familiarity of students under the Project Maths curriculum and the old curriculum with the concept, context, and process of each PISA item on a three-point scale of *Not familiar*, *Somewhat familiar*, and *Very familiar*, and gave separate ratings for students working towards taking a Higher, Ordinary, or Foundation Level Junior Certificate Maths exam. After they had undertaken independent ratings, the raters met to discuss items on which there was disagreement, as well as wider issues in the implementation of Project Maths. On the basis of the meeting, ratings for each item were finalised and the coverage of PISA items in the two versions of the curriculum was determined. There was also extended discussion of the performance of students in Ireland on the Space & Shape subscale.

Table 1: Processes, pre-PM content areas, and Project Maths syllabus strands used in the TCRP

Process	Pre-PM Content Area	PM Syllabus Strand
Recall	Sets	Statistics & probability
Implement procedures	Number systems	Geometry & trigonometry
Connect	Applied arithmetic & measure	Number
Reason mathematically	Algebra	Algebra
Solve problems	Statistics	Functions
	Geometry	
	Trigonometry	
	Functions & graphs	

CURRICULUM ANALYSIS RESULTS

Students studying the Project Maths curriculum were rated as being more familiar with the concepts, content, and processes the PISA underlying items at all syllabus levels than students studying the pre-PM curriculum (Table 2). Even on areas where students of the pre-PM curriculum were rated as *Very Familiar* on average, familiarity ratings were higher for the Project Maths curriculum. Higher level Project Maths students are expected to be at least *Somewhat familiar* with every item and *Very familiar* with more than 80% of them; by contrast, students studying the pre-PM curriculum at Higher level were expected to be *Very familiar* with fewer than 55% of items. For Foundation level students, 25.4% of items were judged to be unfamiliar under the Project Maths curriculum compared to more than half (60.6%) under the previous curriculum. For some items, students were expected to be familiar with the process or with the content area in the given context of the PISA item even if not with the details of the item itself.

Almost all of the items were deemed to be covered by both curricula, 91.5% by the pre-PM curriculum and 97.2% by Project Maths. The most common process underlying the PISA items was Implement procedures (36.6%), followed by Connect (26.8%). Just a few items drew on the skills of Recall (7%) or Solving problems (8.5%). More than a quarter of the PISA items were on Statistics and Probability (28.2%) and more than a third were on Number (38%, corresponding to Number systems and Applied arithmetic and measure in the pre-PM content areas). Just 8.5% of items were rated under Geometry & Trigonometry, suggesting that many of the PISA items on the Space & Shape subscale require knowledge of areas beyond Geometry and Trigonometry.

Table 2: Expected student familiarity ratings for 71 PISA items in the areas of concept, context and process, by Junior Cycle syllabus level for the Pre-PM and PM curricula

	Students Studying Pre-PM Curriculum			Students Studying PM Curriculum		
	Not familiar %	Somewhat familiar %	Very familiar %	Not familiar %	Somewhat familiar %	Very familiar %
Concept – Higher	12.7	32.7	54.9	0.0	18.3	81.7
Concept – Ordinary	19.7	46.5	33.8	7.0	25.4	67.6
Concept – Foundation	52.1	36.6	11.3	25.4	32.4	42.2
Context – Higher	18.3	47.9	33.8	0.0	15.5	84.5
Context – Ordinary	36.6	43.7	19.7	2.8	19.7	77.5
Context – Foundation	59.1	28.2	12.7	8.4	25.4	66.2
Process – Higher	7.1	38.0	54.9	0.0	4.2	95.8
Process – Ordinary	22.5	45.1	32.4	1.4	28.2	70.4
Process – Foundation	60.6	23.9	15.5	12.7	16.9	70.4

Several content areas that are not covered by the PISA items reviewed were also identified: equations, functions, sets, both formal and co-ordinate geometry, trigonometry, and property of number. On the other hand, applied arithmetic and measure and statistics were deemed to be over-represented in PISA. Overall, PISA was considered neither to encompass everything in mathematics nor everything in the Irish curriculum. PISA was also described by the expert raters as linear, with little ambiguity and few opportunities for alternative approaches or lateral reasoning.

Only a small number of the PISA items were deemed not to be covered by the Project Maths curriculum at any level, including items concerning 2-D or 3-D rotation of objects and dealing with links between information on a table and information on a map or chart. There were other examples where information in a narrative description could be used to determine the correct formula to apply in answering the question; students in Ireland are likely to be familiar with the use of the formula but not with the narrative description. Project Maths was considered to have minimal coverage of data tables and the skills associated with interpreting tables.

Raters repeatedly pointed to the literacy demands of PISA items, with the implication that a high level of basic literacy is required to successfully attempt the items. The old curriculum was less reliant on written text than Project Maths and only information and data that were directly relevant to answering the question were provided. No information could be shown on a diagram that was not in the written description. On the other hand, Project Maths is more like PISA in its presentation of information.

The extent to which students might be able to apply skills learned in other subjects to PISA was also considered. Items involving maps and charts might be easier for students who had covered similar material in geography, for example, and students of technical graphics are likely to have a major advantage on PISA Shape & Space items. Similarly, subjects like woodwork, metalwork, and construction studies develop skills that are useful in Space & Shape. However, there are other subjects whose lessons can be applied to PISA items, such as business studies and science and the overlap between mathematics and other subjects was considered bi-directional.

CONCLUSIONS

Overall, the analysis presented here indicates that Project Maths at Junior Cycle level is closer in its conceptualisation to PISA mathematics literacy than the previous curriculum, suggesting that students in IPM schools might be better equipped for the PISA test. Project Maths, then, does show the potential to address some of the long-standing issues in the teaching and learning of mathematics in Ireland, such as teaching by transmission, and moving towards RME.

With respect to the OECD average score and comparison to other countries, concerns had been raised over Ireland's relatively poor performance on Space & Shape, which was significantly below the OECD average in both 2003 and 2012 (Perkins *et al.*, 2013). The same issue was identified across a number of English-speaking countries (OECD, 2013b), and points related to the teaching of geometry and trigonometry were also raised. The curriculum ratings indicate that the Project Maths curriculum may go some way to addressing the historic problem with PISA Space & Shape; the expert raters identified spatial relations and rotational geometry as examples of areas that are likely to improve under Project Maths. However, the complexity of PISA items also means that students are challenged to cross the boundaries between content areas and processes and to think creatively.

The research evidence (Jeffes *et al.*, 2012, 2013; Cosgrove *et al.*, 2012) suggests that teachers have been slow to move to the teaching and assessment style demanded under Project Maths, and this may be due in part to the anxiety caused by the implementation process that is still underway. Professional development workshops were discussed by the three experts in the context of the Shape & Space items but the issues are likely to affect other parts of the curriculum. An emphasis on practical pedagogy was apparent in the workshops with use of manipulables by teachers and of small-group discussion encouraged, for example. However, any of these approaches requires comfort on the part of teachers with using demonstration objects in class and with facilitating group discussion, neither of which can be taken for granted. Changes to how teachers approach mathematics require changes in teachers' and students' expectations of their roles.

For the full report on *Project Maths and PISA* and for further information on PISA 2012, see www.erc.ie/pisa

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Designing, Developing and Evaluating Integrated STEM Activities for Junior Science

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Science and mathematics are closely related in the physical world, yet as school subjects they can be very separate, even where they share overlapping content. Science and mathematics integration has been recommended as a way to increase student conceptual understanding of, interest in, and motivation to learn both subject (Czerniak 2007). Moreover, STEM education (involving the purposeful integration of science, technology, engineering and mathematics) is receiving increasing emphasis in Ireland and elsewhere (Breiner et al. 2012). In this research the STEM focus is the design, development and evaluation of a model that permits teachers to assist students to transfer mathematical knowledge and skills into Junior Science. This resulted in a Critical Integrated Skills and Activities (CISA) Model for developing context-appropriate integrated materials. The model consists of a Syllabus Map of the overlapping content on the Junior Cycle science and mathematics curricula, a Teaching and Learning Sequence for overlapping science and mathematics content and skills, a CISA lesson template for developing integrated lessons, and three exemplar CISA lesson packs. The Syllabus Map and Sequence were evaluated in an earlier stage of the research and one outcome was the need to provide flexibility in the Model so that teachers could adapt it to their local situation and to their students' learning needs. Instead of prescribing the science and mathematics topics that should be integrated, teachers can use the Map, Sequence, lesson template and exemplar lessons to identify critical skills that they may adapt to activities suitable for their science teaching. This paper reports on the design of the CISA exemplar lessons, and of the subsequent evaluation of both the lessons and of the overarching CISA Model, by subject matter experts and by teachers.

INTRODUCTION

STEM (science, technology, engineering and mathematics) education has become an important focus of education policy and research in recent years. STEM education initiatives are generally understood to be concerned with increasing the supply of graduates for STEM careers and educating a citizenry to be more knowledgeable about these disciplines. In a fast-changing increasingly globalized economy, the ability to integrate STEM concepts is a prerequisite for solving the complex and multi-disciplinary problems society faces (Johnson 2013, Roehrig *et al.* 2012). However the conceptualization of STEM education as it would be implemented in teaching and learning is less clear (Roehrig *et al.* 2012). Breiner et al provide a useful conception of STEM education as the 'purposeful integration of the various disciplines as used in solving real-world problems', but there is little shared understanding about the nature of STEM education as an multidisciplinary endeavour (Breiner *et al.* 2012, Roehrig *et al.* 2012).

One of the biggest challenges for primary and second-level education is that few guidelines or models exist for teachers regarding how to teach using STEM integration approaches in their classroom (Roehrig *et al.* 2012). Integration of science and mathematics, for example, has long been recommended as a way to make meaningful connections between these two subjects for students, but models for how to integrate them have been found to vary considerably (Pang and Good 2000, Czerniak 2007). The literature on integrating science and mathematics suggests that how and what is integrated will look different depending on the teacher, the school context, the curriculum and the educational context (Roehrig *et al.* 2012, Stinson *et al.* 2009, Rennie *et al.* 2012). The STEM focus in this research has been into the design, development and evaluation of a model that would permits teachers to assist students to transfer mathematical knowledge and skills into lower-secondary level Science in Ireland. This has focused on finding ways to connect overlapping concepts in the two subjects, but also to take a student-centered approach to teaching and learning in integrated lessons, using inquiry-based learning (Johnson 2013, Judson 2013).

DESIGN AND DEVELOPMENT OF THE CISA MODEL

The CISA (Critical Integrated Skills and Activities) Model for assisting teachers to develop integrated lessons consists of three elements:

1. A Syllabus Map showing how the content of the Junior Mathematics syllabus maps onto the Junior Science syllabus, and an Integrated Science and Mathematics Teaching and Learning Sequence for Junior Cycle
2. A CISA lesson template
3. Three exemplar CISA sets of lessons for Junior Science

In an earlier stage of this research the Syllabus Map and the Integrated Sequence were formatively evaluated by subject matter experts, principals and teachers. The Sequence included the identification, and a brief outline, of six CISA mini-schemes. These were envisaged as short sets of lessons based on the most significant overlapping areas between science and mathematics, as found from the Syllabus Map, but also coordinated with the likely stage of learning of students in both subjects through the Sequence. A common theme in the feedback was that science departments, and, to a lesser extent, mathematics departments, vary considerably in how they sequence topics. Hence it is not possible to define a ‘one-size-fits-all’ set of topics for the CISA lessons that will be identical for every Junior Science classroom. The CISA lesson template was designed and developed, therefore, so that instead of prescribing the science and mathematics topics to be integrated in the CISA, teachers and curriculum designers could use the template, in combination with the Map and Sequence, to identify and design their own lessons. The intention is that the overarching CISA Model for developing integrated lessons offers both robust guidelines, and at the same time is flexible enough to accommodate the varying sequence of topics science teachers follow.

Post-primary teachers do not often get the opportunity to experience integration, nor do they have ready access to integrated instructional materials (Czerniak 2007, Stinson *et al.* 2009). The three sets of exemplar CISA lessons are offered as examples of how the CISA lesson template could be utilised to develop integrated mathematics into science topics that are relevant to the current teaching of science teachers. An integrated ‘Big Idea’, such as the overlap between data analysis in science and relating two variables in mathematics, as per the second CISA lesson pack, is taken as the core concept (Ainley *et al.* 2011). The lessons are then based on specific science topics (for example, relating the amount of solute that will dissolve to the temperature of the solution), but with suggestions for alternative science topics that could be used to explore the same integrated 'Big Idea'. They are a complete set of lessons in their own right, but they are also intended to offer teachers ideas, suggestions and an approach to designing their own integrated lessons.

CISA Lesson Template

The components of the CISA integrated lessons are based on a CISA lesson template (see Figure 1). The backbone of the lessons is the integrated 'Big Idea', but they also incorporate other elements that previous integration research has identified as important. These are: inclusion of syllabus objectives from both subjects, identification of connections and misconnections between the science and mathematics, along with an awareness of the language differences between them (Offer and Vasquez-Mireles 2009, Stinson *et al.* 2009). STEM literacy captures the sense of purposeful integration of the disciplines, while not having to equally include all four in every lesson. In a science lesson, the main perspective would be scientific literacy, incorporating mathematics and the other disciplines as appropriate (Breiner *et al.* 2012). In terms of teaching and learning these integrated lessons are intended to have a student-centred approach (Judson 2013).

Figure 1: The CISA Lesson Template. This shows the components included in the CISA lessons.

The exemplar CISA mini-schemes are designed to support a spiral curriculum of learning of integrated science and mathematics concepts over the course of Junior Cycle. In CISA 1, intended for new first years, students learn about the inquiry process in science and its relation to the data-handling cycle in mathematics. The same inquiry process is used in CISA 2 (later first years) and CISA 3 (end of first year/second year). CISA 1 deals with univariate analysis (counts of single variables in science), while CISA 2 introduces bivariate analysis (paired variables). CISA 3 takes this a step further by focusing on scientific inquiries that result in linear relationships between paired variables. Given how variable the prior knowledge of different groups of students is going to be, both in terms of science and mathematics, the exemplar CISA lessons are intended to permit teachers to adapt the lessons for their own purposes, while still exploring a particular integrated 'Big Idea' with their students.

METHODOLOGY

The methodology for this study is Educational Design Research, which is characterised by iterative design and formative evaluation of interventions in complex real-world settings. Working with practitioners to inform, design, pilot and refine the elements of the CISA Model is an essential part of this methodology (van den Akker 1999). Two prototypes or versions of the exemplar lessons materials were evaluated first by subject matter experts and then by end-users. The method of evaluation chosen at each prototyping stage is related to three generic criteria proposed for high quality interventions: validity, practicality and effectiveness (Nieveen 2009, Plomp 2009, Mafumiko 2006)**.** A 'proof of concept' approach is being used to evaluate the CISA Model. This offers a partial solution to an educational problem, where a full-scale field trial is not yet feasible (Dym *et al.* 2009). Proof of concept is sought through appraisal by experts, practitioners and other stakeholders. It will be possible therefore to make conclusions regarding its 'expected effectiveness' (Plomp 2009), as a process for assisting teachers to design their own integrated STEM lessons. Data is collected via written commentaries, questionnaires, individual interviews and panel discussions, as described below.

The Expert Evaluation Process

A process known as convergent participation was used for the expert review of the integrated lesson materials. It consists of three stages. Initially the evaluators review the learning materials individually. They then send their feedback to a moderator, who amalgamates and summaries their commentary. The experts meet together for a follow-up panel discussion, with the purpose of achieving some convergence of opinion among the reviewers around the changes and revisions that should be made to the material (Nesbit *et al.* 2002). The main concern of this expert review is to obtain formative feedback to help improve the validity and practicality of the lesson packs (Plomp 2009, Nieveen 2009). Science and mathematics experts were asked for their opinion on what changes, if any, they would make to the content of these lessons to a) make them more logical, consistent and accurate with respect to integrating mathematics into science lessons, and b) make them more feasible to use in the day-to-day setting of an Irish Junior Cycle classroom. Experts were also asked to consider the bigger picture where teachers or others would use the CISA Model to design integrated lessons. The main question is: 'Is this Model valid and practical for teachers to use to create their own integrated lessons?'

FINDINGS

Four subject matter experts reviewed the materials. The experts consisted of two third-level educators specializing in post-primary mathematics education, a third-level educator who specializes in primary science education, and a second-level science teacher who develops continuing professional development for other science teachers. Three of the four experts had been involved in the evaluation of the Syllabus Map and Integrated Sequence also. Initial individual written commentary on the materials was reviewed and summarized (Tessmer 1993). Most of the smaller changes were taken on board, while more significant suggestions were put on the agenda for the panel discussion. The review of the materials was generally positive with regard to the validity and accuracy of the science and mathematics being integrated within the lessons. A significant suggested change was to re-structure the lessons materials to account for the differences in teacher knowledge and concerns. By its very nature integrated material draws on skills and knowledge from different subjects. Depending on both the teacher's area of expertise and their students' prior knowledge, teachers may need more or less background information, for example, on how data types and different types of data representations are taught in mathematics class. It also became clear that in designing integrated STEM activities, science teachers can draw on student knowledge from primary science and mathematics, as well as from secondary mathematics, but that many of them may not be aware of this. Hence this information should be included in the revised lessons materials, in a more extensive further information section. With these provisos, the consensus was that the CISA Model could assist teachers to develop their own integrated mathematics into science lessons.

The End-user Evaluation

Once changes based on the expert evaluation had been made, end-users, in this case Junior Science teachers, were asked to evaluate the revised CISA exemplar lessons. 16 teachers are involved. The basic procedure is that teachers read the materials, focusing on one of the CISA lesson packs, and subsequently fill out a questionnaire to give their feedback. Eight of the teachers have additionally opted to try-out some of the lessons in their class room, and this process is on-going. Interviews are also being held with the teachers in order that they can elaborate on their written questionnaire and/or on their experience of implementing the lessons. The focus as before is on issues of validity and practicality of use of the Model in a classroom setting, but also on teacher's views of the expected effectiveness of the lessons in supporting student transfer of mathematical knowledge into science.

Findings from the End-user Evaluation

Initial feedback from the participating teachers suggests the integrated activities are appropriate (practical to implement and in line with the syllabus), and useful for assisting teachers to assist their students to transfer their mathematical knowledge into science. Teachers agreed that they would encourage students to make decisions about the mathematics they require in their science class, are student-centred and will assist them to see the relevance of STEM outside of the science classroom. They liked the lesson activities and materials, and felt they would assist students to make the connections between the science and mathematics. Comments included that the lessons were '*well-structured'*, and '*relevant, i.e., students can see where statistics is applied in everyday life*'. Another teacher said the lessons were 'very good for getting students involved in their own learning. They are constantly discussing, creating their own hypothesis, asking questions, analyzing data and reaching their own conclusions'. Suggestions for change were to do with making the introductory sections and the lesson plans less cluttered with detail; which would improve the readability of the materials. Again the differences in teacher knowledge resulted in science teachers who do not teach mathematics saying that they needed even more '*further information'*, e.g., two newly qualified science teachers made comments about their lack of knowledge of the statistical concepts and of the new Project Maths Syllabus. One teacher commented that she 'might find it hard to relate some of the information to Maths, especially using the same terminology that they use in Maths'. A similar comment had in fact been made by one of the science experts in the earlier part of the evaluation. One of the teachers made specific reference to the fact that she had not previously come across stem-and-leaf plots as a way to represent data. On the other hand, a science teacher who also teaches mathematics felt that the lesson packs could be slimmed down considerably. This teacher did not need as much further information on the relationship to the syllabus and so on. Time for integration is always an issue. The importance of placing these STEM activities within the context of the integrated Teaching and Learning Sequence was highlighted by a comment that 'it would be useful to integrate them into the syllabus with a timeframe'….It would be interesting to see if they would fit into the scheme for the year and still get the same amount of work done'. This teacher had not seen the integrated Sequence, and her concern underlines the need for one, so teachers can feel confident that integrating STEM will not detract from their subject-based teaching.

Overall, those teachers who have provided feedback found the exemplar lessons offer them a good model for developing their own integrated STEM lessons.

DISCUSSION

The evaluation by the participating experts and teachers offers initial proof of concept that the CISA Model, in particular the CISA exemplar lessons, is a feasible process for science teachers to follow so that they can develop their own integrated STEM activities. It was always desirable to have such a model for developing integrated activities available for teachers, as the literature suggests, but this evaluation has also indicated that it may be even more important now than before in the Irish context. Some of the feedback suggests that there is a widening gap in interdisciplinary knowledge emerging in the population of Irish secondary science and mathematics teachers. In the past many science teachers would have developed their mathematical knowledge because they were teaching mathematics, even though they did not have a mathematics qualification. This change in regulations has obvious advantages for the teaching of mathematics as a subject, but, it does mean that the numbers of science teachers with a working knowledge of the mathematics curriculum may decrease. Some studies have pointed to gaps in teacher content knowledge as a barrier to integration; however, it is more accurate to say that while science teachers are skilled end-users of mathematics, they may not have the specific subject-based disciplinary knowledge of mathematics necessary to make the connections for their students (Stinson *et al.* 2009, Roehrig *et al.* 2012). Students need teachers who have interdisciplinary as well as disciplinary knowledge. As Nikitina says, the 'role of the teacher as a translator across different systems of disciplinary representation is crucial' (Nikitina 2006). The CISA Model offers such teachers an otherwise unavailable opportunity to acquire this mathematical pedagogical and content knowledge.

Enhancing STEM education will depend on teachers having a facility to move outside the strict confines of their discipline from time to time, and the CISA Model is one way to encourage this.

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Formative Assessment while Pupils Study Circular Motion

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Pupils studied laws of Circular Motion (CM) by fixing a yarn with a freely hanging screw nut to bicycles spokes. At slow turn rates nut just hang down. A velocity above a certain level keeps the yarn strained. If the wheel rotates at a velocity that just keeps the yarn strained the centripetal force at the highest point of CM results from gravity only. Analysing data at several radii results an estimate of gravitational acceleration g. While performing this pupils were accompanied with formative assessment methods during and after the project to improve teacher's feedback. Contribution shows diverse students' results and teacher experiences.

INTRODUCTION

For several years at the KGS-Sehnde, located in Germany near Hanover, we (physics teacher group) guide the students of class 10 (age 15) through a physics project. Some past examples are: marble-run track, rubber band plane, catapult and circular motion of a bicycle wheel which we present here. Emphasis of the projects is always the report. Neither we can expect perfect experimental setup nor reports ready to be printed.

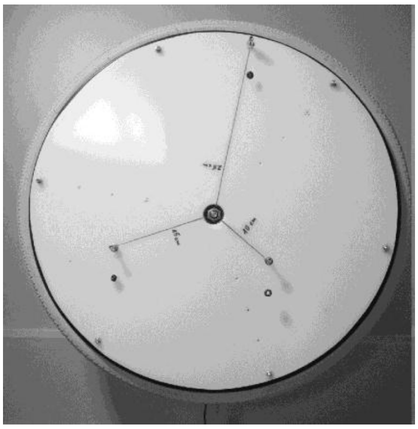

Figure 1: Nuts hanging on a wheel

However because physical and mathematical skills of the students vary very much it is always a challenge for the teacher to assess the students adequately. The aims of the project are:

- inquire fundamental terms of circular motion
- understand the laws of circular motion
- remind and strength inquiry skills like data analysis using diagrams and concepts of linear regression and proportionality,
- find and study relevant literature on their own;
- Also some soft-skills are intended to be developed further, like:
- organising themselves in groups, plan meetings, work together efficiently,
- type writing using ten fingers
- usage of a word processor, and other pc-tools

THE PROJECT: SEVEN WEEKS OF WORK

The project started immediately after the summer holiday. The pupils got a verbal introduction and a introductory paper that clearly points out what is expected (*MATERIAL I*).

Working on the project ran beside normal school operations, but very little homework in physics. While pupils meet weekly for regular physics classes a part of the lesson is reserved for questions raising from the project.

Some years ago we discussed with the pupils weather or not to do a project and what about. The result was a long term discussion about the meaning of such a project and the fact that in other classes there is none (some teachers disagree about doing a project). The school director left the decision whether or not to do a project to the teacher.

If we would have left pupils working on their own until the report had to be handed in, it would be just summative assessment. But formative assessment (observations by the teacher; classroom discussions) caused to change the planed physics lessons according to pupils needs.

Table 1: Timetable of project circular motion (CM)

Week 2013	Planed Project Status	Example: Status Group A	Example: Status Group B	Impact to physics lessons
33	groups get together, discuss experimental setup	appointment for next weekend	New in class; no idea who to work with; too much to do;	Introduction of project work
34	buy all goods necessary.; build experimental setup	Bicycle unhandy; use disk instead, set up takes time	do not know who to ask	Force some pupils to get together
35	Do experiments; get data create a table of data	take pictures, experiments done and got some data	appointment planned for next week	Change curriculum: CM-fundamental terms
36	analyse data: diagrams, linear regression	How to do data analysis ???	Met with classmates; fix of nut is tricky but got some data; internet inquiry	Forces at highest point in CM.
37	write report: diagrams	Do analysis acc. to sample-sheet; relation to g? ask dad, lookup internet; start writing;	Need to hurry; do analysis of data	Example sheet for data analysis + example: (*MATERIAL II*)
38	Write report: physical explanations	No time: other examinations	Rush some diagrams; see report of others	Discussion: elong-ation not acceptable;
39	Critical reflection, list of cost	Write report, reflection, cost- and timetable, digital copy	Write report	How to handle bad data: be fair!
40	Hand over the report	Finish	Finish	collect reports; if so see film / experiment

Giving the pupils an aim i.e. writing a report there was a motor stimulating thoughts and plans. The questions that came up in physics lessons seemed just satisfactory for all of the pupils and answers were returned to be adequate, e.g.:

- when pupils asked for fundamental terms of circular motions the actual physic lesson was changed and we discussed examples like a drilling machine, washing machines, earth rotation and calculated or estimated time periods, frequencies, amplitudes, angular- and track velocity etc.
- generating a diagram v^2 over r was very unusual for pupils. Therefore we decided to do an example data analysis as a worksheet.

However, in future projects some formative assessment methods like a written status reports collected from all groups on a regular basis might help to get an even better insight of work within the groups. In order to discuss with all pupils such a status report could be selected by the teacher or randomly and anonymised.

EVALUATION OF THE REPORT

Figure 2 shows an example result of the pupils experiments. A linear regression to r-v^2 data had a slope of 10,7m/s² (R^2=0,85) fairly near g=9,81m/s².

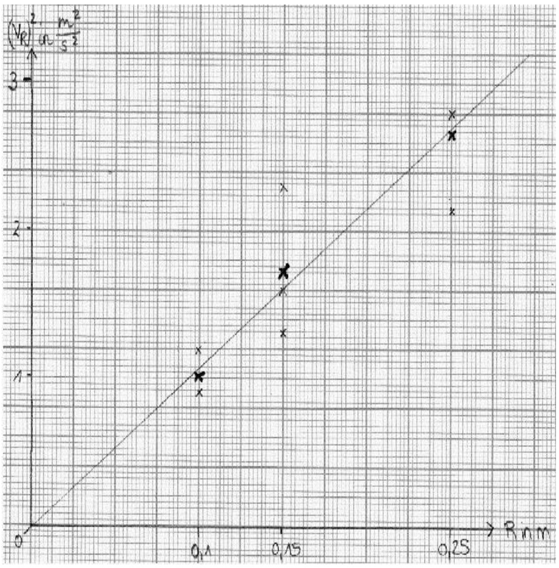

Figure 2: example result:
slope approximates g

Reports were returned to the pupils with feedback according to categories like experimental setup, data analysis using diagrams and computer algebra system (CAS), explanation of physical laws, but also more formal issues like clarity of language and completeness of work.

In order to get to a fair evaluation each group got points to be shared between group members. Given marks did not differ more than three points between group members.

CONCLUSION

Major benefits of the project are:

- getting familiar with inquiry skills in practice;
- motivation that stimulates physics lessons;
- having a common goal;
- improving pupil to teacher relation;

It might be seen critical that marks within groups did not differ for more than three points. Therefore weak pupils somehow hide behind competent classmates leaving all the work for the experts. Also the influence of others like parents and relatives cannot be diverted from the work pupils did themselves. However, we felt that the project should encourage the pupils to cooperate rather than being observed and evaluated individually. And if pupils accepted help it means that there were questions and there was discussion which again is beneficial for learning about circular motion.

For most pupils the project took nearly 20 hours – a weekly average of about 3 hours. Cost were below 15€ in most cases which we think both is acceptable.

FUTURE WORK

The experiment of a hanging nut mounted on a rotating disc might be useful in standard physics lessons. But it cannot be expected that pupils develop the experimental setup on their own. Also it seems sophisticated to estimate g from that approach. Therefore we intend to support the pupils by:

- Giving pupils a description of experimental setup;
- Giving pupils a worksheet that supports data collection, analysis using CAS and diagrams;
- Hints for ambitious pupils, e.g. to think about forces at the highest point when rotation is just fast enough to stress the yarn;
- Introducing regular status reports to be done from all groups and feedback accordingly
- Peer assessment, i.e. group partnerships as a sensitive controlling instrument meant to identify problems in time; teacher involved if needed;
- Present a timescale with milestones that might help the pupils to organise themselves.

MATERIAL I

Physics class 2013 August 2013

Circular-Motion

Tratitionally we start our physics class with a project. Until now pupils did mouse-trap-cars, submarines, rockets, bridges, ships, rubber-band-planes, catapult, marble-tracks and water-rockets.

1. Your Task

Compare the forces that appear at a vertical circular motion with gravity.
Fix a M6-nut at the front wheel of a bicycle, leaving 5cm free space for the nut to swing. Observe the nut at the highest point i) moving the wheel slowly (nut always hanging down) and ii) moving the wheel rapidly (nut will remain outwards). Measure for at least the three radii (distance centre of wheel – screw) R=10cm, 15cm and 25cm the lowest turn rates, i.e. frequencies, at which the screw just remains outwards. Improve the quality of the measurement by taking an average over at least three measurements. For calculation of the turn rates use the speedometer of the bicycle. Note the displayed numbers of the instrument and do all calculation afterwards.

2. Report:

For your project we expect you to write a report, 8 pages maximum, including:

- table of contents
- a digital picture of your experimental setup (important it proves you worked on your own!!)
- a drawing of your experimental setup including values of all length
- description of what you did
- your measurements (raw data) as a table
- two diagrams of your data that show the laws of circular motion, i.g.: 1.) $r - v^2$ and 2.) $1/r - \omega^2$ as x- and y- axes.
- Explain the major physical phenomena, at least balance of forces at the highest point.
- Explain the relation of $g=9{,}81 m/s^2$ to that diagrams above and how g could be determined from those diagrams. Discuss the result.
- list the cost you had and the time you invested for the project (at least an estimations).
- discuss the project critically including conclusions and aspects to improve.
- List literature used
- City, Date and signature of the authors.

The evaluation of your report will also take correctness of language, written style, formal aspects and correct citations into account.

The report is not supposed to be a diary or a builders tuition!

3. Working Conditions:

Cooperate in small groups of 2-3 pupils that you arrange yourself.

4. Hand-in:

Each group has to hand in a printed and a digital version of the report. Both will be returned after evaluation. The digital version will be archived at school.
Handing in has to happen in the last physics lesson before autumn holidays. A later hand in will not be accepted. In case nothing was handed in evaluation will be lame.
If you wish to show your experiment at school, let the teacher know in advance. This will improve your evaluation.

5. Evaluation:

Most important for the evaluation of the project is the report. The project contributes to your verbal evaluation of the first half year.

Good luck, your Physics teacher Dr. Wunder

Figure 3: Project Introduction

MATERIAL II

Analysis of circular motion at bicycle wheel

Fundamental Terms:

Circumference $\boxed{U=2\cdot\pi\cdot R=\pi\cdot D}$ (1)

Time-Period: T (Time per round)

Track velocity at radius R: $\boxed{v_B=\frac{U}{T}=\frac{2\pi R}{T}}$ (2)

Example: Wheel with diameter D=28Zoll=0,71m => U=2,234m

If the bike goes v=20km/h=5,55m/s one round of the wheel takes

because of (2): $\boxed{T=\frac{U}{v_B}=\frac{2{,}234\,m}{5{,}56\,m/s}=0{,}40\,s}$

A position with radius r=0,1m has the track-velocity:

$\boxed{v_r=\frac{2\pi r}{T}=\frac{2\pi 0{,}1\,m}{0{,}40\,s}=1{,}57\,\frac{m}{s}}$

In order to calculate the track velocity $\boxed{v_r}$ from $\boxed{v_B}$ of the bike one gets:

$\boxed{\underline{v_r}=\frac{2\pi r}{T}=\frac{2\pi r}{U/v_B}=\frac{2\pi r}{2\pi R}v_B=\underline{\frac{r}{R}v_B}}$ (Attention: convert km/h in m/s !) (3)

Procedure:

1. Fix the yarn so that the freely down hanging screw-nut is a radius of e.g.: r=0,1m.
2. Turn the wheel and observe the nut at the highest point. If the yarn is no longer straight note the velocity that the speedometer shows. This is $\boxed{v_B}$.
3. From $\boxed{v_B}$ compute $\boxed{v_r}$ using formula (3).
4. Repeat all measurements at least three times and calculate the average. Do that at different radii.
5. Data analysis using spreadsheet and Diagram:

	r	v_B	$v_r=\frac{r}{R}v_B$	$(v_r)^2$	
Example not typical!	0,1m	5,56m/s	1,56m/s	2,44m²/s²	
	0,1m	5,45m/s	1,53m/s	2,35m²/s²	
	0,1m	5,72m/s	1,61m/s	2,59m²/s²	
				2,46 (m/s)²	Average

Diagram: $\boxed{(v_r)^2}$

Draw a straight line trough data points (linear regression) and estimate the slope of that line. Compare that slope with physical constants you are familiar with.

Hint: the diagram above has its meaning for your measurements, not the example in the table above.

Figure 4: Data Analysis

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