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Diving Deep into Numeracy, Reflections by Teachers on their Professional Development Project

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This report describes a two-year project, titled 'Numeracy Deep Dive Project' to encourage teachers of mathematics and other subjects develop numeracy competency in their schools. The purpose was to explore how numeracy can be integrated in a meaningful and constructive manner in a range of carrier subjects at post-primary and how these subjects can, in turn, influence the manner in which relevant concepts can be addressed in mathematics lessons. The feedback and the analysis of results demonstrate success in developing numerical comprehension across the curriculum underscoring the value of quantitative literacy.

1 Introduction

Numeracy and numerical comprehension is critical to educational development and is identified as being vital for all students to achieve during their time in school and into the future - so learners can fully participate in society, in family and community life. The 'Deep Dive in Numeracy' project was designed and implemented against a very rich and challenging policy landscape and this report describes a project by the Professional Development Service for Teachers (PDST) and the Department of Education and Skills Inspectorate. This report describes on a project highlighting the importance of teaching numeracy across the curriculum and across subjects, encouraging and promoting understanding necessary for learning, educational growth and development.

The aim of the Numeracy Deep Dive Project was to encourage and foster teacher collaboration, in pairs and in the design of the lesson or series of lessons encouraging numeracy development across the whole school. The purpose of the Deep Dive in Numeracy project is to embed numeracy in a meaningful and constructive manner in a range of carrier subjects at post-primary and ensure these subjects can, in turn, influence the manner in which relevant concepts can be addressed in mathematics lessons. The results from the third year of the project are described focusing on teacher reflections and professional development.

2 Theoretical Framework

There is no universally accepted definition of numeracy (O'Donoghue, 2002) however in 1959 the word numeracy was first used to mirror the meaning of literacy (Cockcroft, 1982). Baker et al in 2003 examined numerical events as "occasions in which a numeracy activity is integral to the nature of the participants' interactions and their interpretative processes" (Baker, Street, & Tomlin, 2003, p. 12). They also use the term numeracy practices which "are not only the events in which numerical activity is involved, but [...] the broader cultural

conceptions that give meaning to the event [. . .]" (Baker et al., 2003, p. 12). Numeracy therefore embraces all aspects of being a mathematical thinker and is much more than being able to calculate with fluency and accuracy. Barton and Hamilton (1998) give examples of activities involving numeracy observed in their research such as gardening, cooking, sewing; following current affairs with charts and diagrams in the newspaper; health and medicine; finances to name but a few (Barton & Hamilton, 2012, p. 177). The term numeracy therefore may signify any one of a number of things including, basic computational arithmetic, essential mathematics, social mathematics, survival skills for everyday life, quantitative literacy, mathematical literacy and an aspect of mathematical power (O'Donoghue, 2002). Numeracy involves the transferable skills needed to think critically, to communicate effectively and to make a full contribution to society in this increasingly data-rich world.

Numeracy involves mathematical proficiency, it is however less abstract than mathematics and has immediate relevance in the lives of students (Steen, 2001). Numeracy or being numerate is about using mathematics to act in and on the world, people need to be numerate in a range of *contexts* (Goos, Dole, & Geiger, 2011). Numeracy is not another topic to be added to mathematics specification but rather involves context and the use of numbers, calculation or diagrams in social practice; whilst mathematics involves some degree of abstraction or concern with structure (Barwell, 2004; Steen, 1999). Numeracy encompasses the ability to use mathematical understanding and skills to solve problems and meet the demands of day-to-day living in complex social settings and there is an expectation that teachers are aware of the numeracy demands of their subject - specific to their subject - and that they address these in class as the opportunities naturally arise. The context is both a real-world everyday context and the curriculum context at school.

Department of Education and Skills (DES) policy informs this project such as the National Strategy to Improve Literacy and Numeracy and STEM strategy (DES, 2011, 2015a,

2016a, 2016d) and international reports such as PISA and TIMSS (Grønmo, Lindquist, Arora, & Mullis, 2015; OECD, 2013; PISA, 2006). At post-primary level, Irish students' performance in PISA 2012 was above the OECD average, which on the face of it was an improvement compared with previous cycles of PISA. However this did not represent an improvement in absolute terms, as the average performance across OECD countries had fallen since previous cycles. The performance of Irish students in numeracy in international and national assessments was weaker than for literacy, particularly among higher-performing students (DES, 2016c). The project implementation was also particularly shaped by a report titled 'Promoting and Improving Numeracy across the Curriculum in Post-primary Schools' (DES, 2015b). That particular report was prepared by Education and Training Inspectorate of Northern Ireland and the Department of Education and Skills in the Republic of Ireland who were commissioned to research and report jointly on the key features of successful teaching and learning in literacy and numeracy at post-primary level by a Working Group of the North/South Ministerial Council. The 'Promoting and Improving Numeracy' report " (DES, 2015b) found that numeracy in subjects other than Mathematics is most effective when teachers project a positive attitude to the use of mathematics in his or her subject; explore authentic contexts which are integral to the learning of his or her subject; use explanations, and teaching approaches, in line with those used by the mathematics department and the other main carrier subjects; make explicit the 'cognitive conflicts' that arise when the same ideas are interpreted differently in their subject and in mathematics, in order that their students embrace and resolve them; and support individual students, at the point of need, with the mathematics required in the learning of his or her subject.

These findings correspond with research in mathematics education and professional development communities (Bonner, 2006; Graven & Venkat, 2007; Hill, Schilling, & Ball, 2004; Tall & Vinner, 1981). Darling Hammond at al (2005) proposed a teacher professional

development framework which should have shared educational values, guiding vision of good practice, deep knowledge of content pedagogy, student and social context as well as deposition to reflect and learn from experience (Darling-Hammond, Hammerness, Grossman, Rust, & Shulman, 2005).

Teacher professional development is critical to improving the quality of schools, teacher instruction, and student achievement, making it a focus for education policy and reform. In Ireland the Professional Development Service for Teachers (PDST) was established by the Department of Education and Skills (DES) in 2010 to provide quality professional development and support to empower teachers and schools in the provision of the best possible education for all pupils/students (PDST, 2015). The PDST is a support service operating under the aegis of the DES supporting teacher professional learning, collaboration and evidence-based practice and place specific emphasis on curriculum and pedagogy, learning and teaching methodologies. Supportive professional development is critical to implementation of policy, enabling teachers keep abreast of advancements in best practices, as well furthering knowledge and skills (Borko, Jacobs, & Koellner, 2010; JC Sleegers, EJ Thoonen, J. Oort, & TD Peetsma, 2014; Shulman & Sherin, 2004).

3 Research Design

The most transformative type of professional development situates subject-specific teacher learning within communal contexts (Borko et al., 2010; Frykholm, 1998; Shulman & Sherin, 2004) and the Numeracy Deep Dive Project involved teachers identifying and agreeing material to be explored and in creating authentic contexts to facilitate its exploration. The project involves pairs of teachers and a community of practice, one who teaches mathematics and another teacher of a carrier subject. Taking place in post-primary schools nationwide in Ireland, the project fostered collaboration in lesson design with a particular focus on

developing students' numeracy and mathematical skills. The focus of the collaboration was to recognize and exploit authentic examples of numeracy and mathematics in the carrier subjects and to co-create lessons which treated the mathematical concepts in a rigorous and context-rich fashion. In offering multiple cross-curricular possibilities, teachers choose their topics within subjects, affording adequate overlap between the learning outcomes on the mathematics specification and those of the identified carrier subject.

The Deep Dive in Numeracy project commenced with a pilot project in AY2016/17 involving three schools. Outcomes from the pilot study included motivational gains by students who perceived mathematics to be challenging. Due to the positive reception and outcomes by the three pilot schools and by the six schools in AY2017/18, a plan to support a greater number of schools involving the integration of mathematics with an increased variety of carrier subjects was considered and developed. It was decided that Deep Dive in Numeracy would be continued in AY2018/19 with the PDST supporting schools who elected to participate and that consultation with the Inspectorate, which was a feature of the earlier iterations, would also continue. When potential carrier subjects were identified, schools were contacted to gauge their interest. This resulted in the initial involvement of ten schools who elected to progress work on a Deep Dive in Numeracy between a teacher of mathematics and a teaching colleague of a carrier subject. Two schools subsequently withdrew at this juncture due to timetabling constraints. The nature and range of collaboration of those schools who remained is illustrated in Table 1.

Table 1. Participant schools by Carrier Subjects, Year groups and Number of classes.

School	**Carrier Subject Area**	**Type of Artefact created during Deep Dive**	**Year group**	**# Mathematics class periods**	**# Carrier Subject class periods**
School 1	Design Graphics	Graphs using GeoGebra 3D models	1st	3	3
School 2	Geography	PowerPoint	2nd	3	3

		GeoGebra Worksheets Video			
School 3	Science	Models Scaled drawings Excel	1st	3 (1h)	3 (1h)
School 4	Art	Exhibit for graduation ceremony	LCA		
School 5	Science	Data collection and Graphing Minion worksheet on plotting co-ordinates	1st	3	4
School 6	Business	Research project Worksheets	1st	4	6
School 7	Science	Worksheets	3rd	8	8
School 8	Biology	Booklet	TY	7 (1h)	7 (1h)

Five meetings with teacher pairings were facilitated between November 2018 and May 2019. One of these was a full-day six-hour event while the duration of the other meetings was two and a half hours. In the first few meetings the focus was primarily on conveying the context and purpose of the project to teachers, as well as defining the duration of the project. The aim of the meetings was also concerned with developing co-professional dialogue between collaborating teachers and the PDST advisor assigned to support them. The teachers identified their roles and work implications including key dates regarding the timeframe of collaboration and implementation while also agreeing potential dates of support visits by PDST advisors to the participating schools.

The meetings and PDST visits assisted teachers as they created new windows of opportunity to plan, enabling the sequence of work within an agreed timeframe. In some cases colleagues switched timetables/classes to facilitate team-teaching and others, amended their curricular plans in both mathematics and the carrier subject. Teachers often communicated electronically using WhatsApp and email for example, as face-to-face discussion in the staffroom was not always feasible. In cases where face-to-face

communication was possible, break time, lunch time or end of week planning occurred. The teachers who were team-teaching in mathematics classes noted the benefits of this approach especially if they also taught some of the same student cohort within the carrier subject. For some, teachers found that having an already established relationship with their colleague was useful and the interaction lead rapport and trust which served to facilitate collaboration and fostered creativity. In all cases, learning outcomes and related learning intentions provided the detail of how teachers envisaged student learning progressing in an authentic manner, allowing students take ownership of their work.

4 Findings

A relatively wide range of teaching and learning approaches were used to actively engage students as they developed numeracy skills in a manner where they made links between mathematics and various carrier subjects. Approaches adopted included inquiry-based learning, team teaching, cooperative learning, think-pair-share, classroom debates and discussions, peer assessment, directed questioning (higher order and lower order), problem solving worksheets, Quizzes and summative assessment, using technology such as GeoGebra and 3D (scaled) model making to visualise mathematical concepts, student portfolio work and reflections as well as the teacher reflective journal. It is worth noting that while the focus on collaboration between mathematics teachers and those of various carrier subjects was enhancing students' numeracy skills, additional benefits involving students' literacy naturally accrued from the pedagogical approaches employed. This occurred as the students engaged in activities such as the creation of audio files in OneNote, written explanations of graphs, group discussion / debate and the presentation of work to peers.

One example is School 5 AY2018/19 where the teachers of mathematics and science collaborated and introduced technology such as GeoGebra into the planning. Their project

was called ‘Spinner Investigation’ and the rationale was to understand that without air resistance all objects will fall at the same rate. With the aid of mathematics the aim was that the students would develop a deeper understanding of both the science being taught as well as a greater appreciation of the mathematical applications being used. A detailed discussion was conducted between both cooperating teachers and writing in their reflection stated *“we decided on a topic that would fit best into our curriculum within the timetable - that would beneficial to the learning and understanding of our students. We met over coffee breaks, free classes, conversations on the corridor and of course meetings in the Science laboratories. Our plan is for the experiment to be conducted over one double and one single class (9th & 11th April). It will tie in perfectly with the ‘Science of falling bodies’ section of our Science termly plan”* (Teacher1 S5.) The intention was that the mathematics class would then take the data and help to improve student understanding and learning by representing the data graphically. Both teachers engaged with each-other throughout the process to ensure the work was on schedule and to plan. The maths class then uses the data in the first week after Easter holidays (1st-3rd May), and then brought their findings back to the science laboratory to discuss and report in a final single Science class (~May 7th).

The students unknown to themselves, discovered they would get data easier to interpret if they changed <u>one</u> variable only .e. keeping the height constant at 1.9 metres and then changing the number of paperclips. They also had to determine the flight path of the spinner and repeat the experiment many times to determine the average - thereby eliminating outliers. The students used phones and stopwatches to determine the time, they considered their reaction times and how they might improve on these in the future. In refection the teachers commented *“This was an excellent project to introduce to first year students. These students, with no second-level experience, were open to the idea that there was a common language used in both Mathematics and Science. They also brought their collaborative skill set from*

*Primary school with them - thereby overcoming the usual inhibitions that second level students experience when introduced to group work in 3rd year" (*Teacher2 S5.) This project was deemed a success as students applied their mathematical knowledge into Science lessons seamlessly. It was noted that engagement between teachers from different subject departments also increased which contributed to overall school improvement, strengthening links between the Mathematics Department and other disciplines, introducing common mathematical language.

An inquiry-based learning approach was adopted by School 4 where the Mathematics department and the Art department collaborated. This school has over 200 hundred 6th year students and they wanted to have artwork from every student on display at the graduation ceremony "*We don't have a huge space to display our art so the LCA students had to create a suitable sized piece of card for their fellow students to create their artwork. They then had to create a way to display every students artwork in an equal fashion*" (Teacher1 S4.) The Art class was asked to create the Graduation Ceremony backdrop, Figure 1. In the mathematics planning grid, the topic of scale, shapes and constructions were topics to be covered with links to Art. The learning intention of the project was that "students would be expected to answer questions relating to scale, understand the concept of scale and the reasons for using scale. Students should be able to translate between scale lengths and actual lengths on drawings, photographs, and models and draw both sketched and diagrams to scale." This project gave students ownership of a large visual part of the Graduation ceremony and highlighted the skills they have learned during the academic year. It was found the more teachers got involved, the greater the focus which in turn brought about better participation from the students. The Maths teacher commented "*We had worked on so many scale questions in class, as it is the research topic in this year's leaving cert, the class really*

enjoyed putting their skills to work and showing their Art teacher what they could do"

(Teacher2 S4.)

Figure 1. Graduation ceremony artefact, developed in Mathematics and art class, School 4

4.1 Formative assessment

Formative assessment was a fundamental teaching and learning strategy employed by the teachers as they embarked on this novel approach to the development of numeracy skills among their students. In addition to learning gains, the teachers could gauge the impact of the numeracy initiative relative to traditional approaches that they used in the past. It provided a lens through which the participating teachers could reflect on to see if the new approach had merit. The techniques employed included approaches such as: the development of success criteria in the form of a rubric in mathematics by students and their subsequent employment, for example, in their self-evaluation of previously drawn graphs in their carrier subject; Levels of questioning (higher and lower order); Questioning of students studying a carrier subject by the mathematics teacher on content knowledge, previously unfamiliar to the teacher, that related to the carrier subject (thus allowing the teacher to facilitate learning by students explaining their work to their peers); Quizzes using Microsoft forms; Mind maps to

consolidate learning; Student portfolio of work; The use of 'Flipgrid' to gather student reflections; Student whiteboards / show-me boards; Formative Feedback using two stars and a wish; Google Classroom/Microsoft teams; Making scale models; MS Excel (for graph analysis); and peer assessment.

4.2 Benefits to Teacher Practice and Professional Learning

The collective sentiments expressed by participant teachers regarding the impact on classroom teaching and learning resonated with statements of highly effective practice within the Teaching Dimension of the Department of Education and Skills 'Looking at Our Schools' report (DES, 2016b), particularly Domains 1 (Leading Learning and teaching) and Domain 2 (Managing the Organisation). It was evident from the wide variety of projects that all of the Junior Cycle key skills were addressed in some way through these collaborative numeracy projects.

The Framework of Key Skills (NCCA, 2009; Rychen & Salganik, 2003) and the key skills were evidenced in the cross curricular project work. One teacher participant explained that students had to present their work in multiple forms which naturally brought all the NCCA key skills into focus in addition to affording them the opportunity to be numerate. Another teacher identified the development of additional skills such as problem solving and critical thinking in the work. Examples demonstrating the skill of 'Staying Well' was evidenced through the wide variety of activities such as collecting data, working as a group, investigation and inquiry-based learning which allowed students to work on their confidence in a healthy, active and physical way. The skill integration observations align with research findings in Australia (Geiger, 2014; Goos, Dole, & Geiger, 2011; Morony, Hogan, & Thornton, 2004).

The project approach was deemed effective in terms of making mathematical concepts visible and meaningful for students rather than students having what one teacher referred to as "*a very compartmentalised vision of their subjects in school. The cross curricular approach to topics not only engaged students more but also led to a great ownership and pride in their learning*". This observation reiterates the work of Bruner and other social constructivist theorists (Bruner, 1973). Student learning and engagement was much greater as they were motivated by the fact that they could see the potential uses and applications of mathematical knowledge and skills in other areas of learning (Núñez, Edwards, & Matos, 1999; Skemp, 1983). While participants made reference to the ability of students to see the link between carrier subjects and mathematics, in some cases students were able to extend this awareness and identify links beyond the carrier subjects (Gerofsky, 1996).

Participating teachers commented that students had an increased understanding, motivation to learn and retention of concepts explored (Furrer, Skinner, & Pitzer, 2014; Hargreaves, 2000). Indeed, non-participant students who were aware of other classes where the Deep Dive Numeracy project was being employed sought to know why they "*could not collect data in science class and use it in maths class*" and asked their chemistry teacher "*to get onto the other teachers and tell them they have to do this*". It was apparent that student motivation was enhanced when students collected primary data which provided a real-world context for them as opposed to data taken from a textbook. Using this approach brought a familiarity to the student learning process rather than a belief that they were learning about abstract phenomena. It also created visible links for students between mathematics and the outside world (Blum & Niss, 1991; Warren, Ogonowski, & Pothier, 2003), indicative of the improved learning experiences for students was the increased attendance levels in classes. This phenomenon was echoed with a separate cohort of students in different school

participating in the Leaving Certificate Applied programme where student attendance was often problematic and now the teacher was providing students with an opportunity to discover things by themselves (Pólya, 1981).

All teacher participants commented on the change in attitude of the students who were willing to readily take responsibility for their own learning. One teacher noted "*students were engaged in their learning, were eager to get work done, student motivation levels went through the roof*". Another stated that "*This project has shown me that small changes to lessons can have a huge impact on learning and attitude to learning with students*." As a result the relationship between students and their teacher was positively impacted leading one teacher to surmise that the outcomes of this project would indicate that there is a greater need for future cross-curricular collaboration. Student engagement in teaching and learning allowed some teachers to see that the experience was preparing their students for forthcoming Junior Cycle, Classroom Based Assessments (CBA's). Observations and feedback by teachers based on the impact of co-professional planning with which they engaged are also consistent with the statements of highly effective practice from Domain 3, (Leading School Development) of the DES Quality Framework (DES, 2016b) and with literature (Geiger, 2014; Goos, Geiger, & Dole, 2014; Wineburg & Grossman, 1998). For most of the teacher participants, it was the first occasion that they conducted planning in a structured and collaborative way. The efforts often led to teachers developing their capacity to envisage future benefits and possibilities related to teaching a topic in mathematics in tandem with a carrier subject. In addition to bringing their practice to within the range of those regarded as highly effective, teachers described how they had learned new techniques/methodologies to enhance students learning. The Deep Dive in Numeracy project also enabled them to receive collegial support when planning or dealing with difficult situations. It ultimately saved time when teaching a topic, thus allowing for other areas to be further explored in terms of

teaching and learning and receiving validation from students regarding the positive impact their practice was having on learning and served as a definite highlight.

4.3 Challenges

The principal challenge for teachers was the time constraint regarding attempted planning. Responses indicated that it would have been more beneficial if it more time was made available to consider the practicalities involved and to align schemes of work between mathematics and the carrier subject. One aspect of participant planning to optimise collaboration included identifying the topic to be taught concurrently four months in advance while mutually agreeing a teaching schedule to implement teaching and learning two months in advance. However, participation in the Deep Dive meetings where a Community of Practice developed offset this to a certain extent, as did communicating through email and having short, informal conversations with colleagues. Teachers used WhatsApp and email to communicate and collaborate in cases where they did not have the opportunity to meet face to face. Other challenges, particularly when teachers were attempting to engage students was in reducing class contact owing to out-of-school activities (typically transition year (TY) students); irregular attendance of students and the schedule of work was disrupted if teacher was absent or if there was a school event. In some cases curriculum alignment proved difficult.

Teacher participants highlighted the importance of good relationships with colleagues helped to assuage some of these challenges. As challenges were surmountable, most participants identified that they would continue collaboration with colleagues on numeracy topics in new areas of learning next year. To enable this to occur, a number of teacher pairs were planning to present their results and reflections to the entire school staff at a staff meetings. Two groups intended to meet with their school management to update them and

discuss plans to bring other subjects on board and involve other year groups, while others plan to present their findings at national teacher professional development and research fora.

5 Conclusions

The Numeracy Deep Dive Project involved pairs of teachers, a teacher of mathematics and another teacher of a carrier subject, who engage in co-professional lesson planning and design (mathematics and science, mathematics and business, mathematics and art, mathematics and technical graphics). The agreed area of focus was on an area of numeracy common to both subjects. It resulted in an authentic, rigorous treatment of mathematical concepts in a collaborative fashion that was without precedent for those who participated.

As students were emotionally connected to their work, they saw ‘a direct link’ between the carrier subject and mathematics. Their capacity to contextualise concepts within both subjects led to an increased tendency to transfer and apply ideas across them. This was often aided by working with primary data they had generated in the carrier subject which led to visible links between mathematics and ideas from the real world. Affective benefits in addition to cognitive benefits accrued to students as they gained clarity on what was required of them in order to be successful and to subsequently self-assess. As a result, the metacognitive nature of their engagement with learning grew. Students became increasingly reflective regarding how they themselves learned and how their peers learned. Confidence among students also increased which led to creativity, confidence and enjoyment while developing students’ literacy skills and understanding in mathematics.

The project resulted in an unprecedented level of collaboration between participants from the same school within a STEM subject setting. As a consequence, cross-curricular links were forged and plans were made regarding the achievement of student learning outcomes in areas of commonality between mathematics and a carrier subject. While the

Senior Cycle was not the focus of the Deep Dive in Numeracy 2018-2019, it potentially has positive implications for the students who engaged in it regarding horizon concepts underpinned by the mathematics specification. Participant teachers reflected that to make gains in professional learning within the parameters of the project, an honesty, openness and flexibility towards colleagues is required. The main challenge for teachers using this approach was time for the planning of joint lesson design which was largely attributed to the hectic nature of school life and inexperience with cross-curricular collaboration. However, challenges were not seen as insurmountable and teachers demonstrated a willingness to engage in and expand their range of collaborative experience with their colleagues.

It is intended that a further cohort of schools will partake in an extension of the project in the coming academic year. The key messages and learning arising from the project will inform the planning and direction of the future Deep Dive in Numeracy. The range of carrier subjects that will be considered is also likely to increase to include other subject areas, such as geography for example. Considering evidence gathered regarding challenges encountered the implementation of future Deep Dive in Numeracy projects will include an emphasis on the use of digital tools and a more considered pace of teaching and learning that is conducive to jointly proposed teaching and learning plans.

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