Diving Deep into Numeracy, Cross Curricular Professional Development

The numerical ability of Irish students in international and national assessments is weaker than for literacy, particularly among higher-performing students. The aim of this study was to design a national teacher professional development programme to encourage teachers at post-primary level to develop numeracy competency across the post-primary curriculum. The project explored how numeracy and mathematics can be integrated meaningfully and constructively in a range of carrier subjects and explore how these subjects can, in turn, influence the manner in which relevant concepts can be addressed in mathematics lessons. The theory underpinning the effective design followed a model of professional development incorporating four strategies. The study was conducted over three school years and the pedagogical approaches adopted by teachers in the cross-curricular integration of numeracy are presented. How the approach supported teachers' learning is also presented according to a model of teacher agency in professional development and school reform, examining (i) individual practice (ii) outcomes (iii) perceived work context and (iv) school reform. The discussion points which arise describe the community of practice which evolved, and the readiness of the participant teachers to embrace professional development in preparation for curricular reform.

Keywords: numeracy; professional development; whole school

Introduction

At post-primary level the performance of Irish students in numeracy in international and national assessments was weaker than for literacy, particularly among higher-performing students (O'Donoghue, 2018). Results from the Program for International Student Assessment PISA informed national policy such as the National Strategy to Improve Literacy and Numeracy and STEM Education in the Irish School system strategy (DES, 2011, 2016b) and international reports such as TIMMS (Grønmo, Lindquist, Arora, & Mullis, 2015). Numerical competency ensures that each child is able to think and communicate quantitatively, make sense of data, have a spatial

awareness, understand patterns and sequences, and recognise situations where mathematical reasoning can be applied to solve problems (DES, 2011).

The curriculum offered by a school and received by students, should not be simply a collection of separate subjects (Kelly, 2009) and viewing curriculum as solely a syllabus is detrimental to student and societal development. When teachers have a deep understanding of the concept of numeracy, and an awareness of the essential role it plays in allowing an individual to fully engage in society, then the inclusion of numeracy will play a more significant role within their discipline subject (Bennison, 2015; Goos, Geiger, & Dole, 2014). The 'Promoting and Improving Numeracy' report by the Working Group of the North/South Ministerial Council reiterated the research with the report finding that numeracy in subjects other than Mathematics are most effective when teachers project a positive attitude to the use of mathematics in the alternate subject (DES, 2015). The cross-curricular recommendations were reinforced recommending teachers explore authentic contexts which are integral to the learning of subjects, using explanations, and teaching approaches, in line with those used by the mathematics department and the other 'carrier' subjects. They further advise to 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 (DES, 2015).

This paper presents findings from a national teacher professional development programme to encourage and foster teacher collaboration in embedding numeracy across the post-primary curriculum. The national project was designed systematically and had the support of the Professional Development Service for Teachers (PDST) and the Department of Education and Skills (DES) Teacher Education Section (TES). The design of the professional development programme was modelled on the four strategies

for professional learning (Loucks-Horsley, Stiles, Mundry, Love, & Hewson, 2009). The purpose of the project, titled "Numeracy Deep Dive" was to explore how numeracy and mathematics can be integrated meaningfully and constructively in a range of carrier subjects at post-primary and explore how these subjects can, in turn, influence the manner in which relevant concepts can be addressed in mathematics lessons. Taking place in post-primary schools nationally, 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 in both mathematics and the carrier subjects, and to co-create lessons which treated the mathematical concepts in a rigorous and context-rich manner. The project adopted an action research methodology. The research questions presented in this article are: What pedagogical approaches were adopted by teachers in the cross curricular integration of numeracy? How well did this professional development approach support teachers' learning?

Theoretical Framework

Teacher professional development can be defined as those processes and activities designed to enhance the professional knowledge, skills and attitudes of teachers on an individual level so that they might, in turn, improve the learning of students (Guskey, 2002). Models related to teacher professional development focus on teacher change (Guskey, 2002), professional development (Desimone, 2009), teacher learning (L. Shulman & Shulman, 2004) and professional growth (Clarke & Hollingsworth, 2002). Supportive professional development is critical to the implementation of policy, enabling teachers to keep abreast of advancements in best practices, as well furthering their knowledge and skills (Borko, Jacobs, & Koellner, 2010; Sleegers, Thoonen, Oort, & Peetsma, 2014; Shulman & Sherin, 2004; Harris, Stevens, & Higgins, 2011). The

model adopted for this study and for the effective design of Numeracy Deep Dive professional development is based on that of Loucks-Horsley et al. (2009). This model was appropriate and an effective professional learning model for numeracy as it focuses "on evidence-based teaching practices, such as facilitating meaningful mathematical discourse and implementing tasks that promote reasoning" (SRI 2019).

Numeracy in our Education System

An initial reference to numeracy was made by Crowther in 1959 and the relationship between quantitative and verbal literacy was emphasised as he states that "numeracy should represent the mirror image of literacy." (Cockcroft, 1982). The value of being numerate cannot be understated and in an era of data, quantitative literacy joins verbal literacy as the guarantor of liberty, both individual and societal (Steen, 1999). Baker et al. 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). 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 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, 2006).

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, 2011b).

> *"Mathematics climbs the ladder of abstraction to see, from sufficient height, common patterns in seemingly different things. Abstraction is what gives mathematics its power; it is what enables methods derived in one context to be applied in others. But abstraction is not the focus of numeracy. Instead, numeracy clings to specifics, marshalling all relevant aspects of setting and context to reach conclusions. To enable students to become numerate, teachers must encourage them to see and use mathematics in everything they do. Numeracy is driven by issues that are important to people in their lives and work, not by future needs of the few who may make professional use of mathematics or statistics." (Steen, 2001, pp. 17-18)*

Numeracy consequently 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, Roux 1979). 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. Numeracy has a purpose, problem solving or critical; and critical numeracy can be promoted both within mathematics and outside of mathematics – it is the ability to make discerning decisions about everyday issues that involve mathematical concepts.

Programmes to embed numeracy across the whole-school need to involve teams of people, including those with and without mathematical interests and expertise, working together to understand issues and develop strategies and approaches (Morony, Hogan, & Thornton, 2004; Thornton & Hogan, 2004). As numeracy describes the aggregate of skills, knowledge, beliefs, dispositions and habits of mind as well as communication capabilities it is key that such programmes enable students develop problem solving skills to handling real-world situations with embedded mathematical or quantifiable components (Gal, 1995). There is a conscious effort being made to improve

and raise the profile of the teaching and learning of numeracy internationally (Askew, 2015; Bennison, 2015; DES, 2011; Goos et al., 2014). If teachers have a deep understanding of the concept of numeracy, and an awareness of the essential roles it plays in allowing an individual to fully engage in society, then the inclusion of the teaching and learning of numeracy will play a more significant role within their discipline subject. Pre-service initial teacher education programmes, do not usually address the role numeracy plays in disciplinary understanding (Goos, Geiger, Dole, Forgasz, & Bennison, 2019). Therefore if teachers, upon graduation from their accredited teacher education programme, do not recognise the opportunities available to them to develop numeracy competencies among their students, the onus is on professional development (Teaching Council, 2016).

Teacher Agency and Curriculum Enactment

Numerical knowledge and skills developed throughout the curriculum are key, but also of concern is how we assess and evaluate what needs to be built in, so therefore it is also about pedagogy. Sense making is implicated in curriculum as it is enacted from policy to practice (Blignaut, 2008; Klein, Moon, & Hoffman, 2006; März & Kelchtermans, 2013). In order to embed a numeracy teacher professional development programme, we need to continually develop the professionalism of teachers and the agency of teachers (Priestley, Biesta, & Robinson, 2013). Within the discourse of agency, teacher agency is considered a specific form of professional agency—their active contribution to shaping their work and its conditions is assumed to be an indispensable element of good and meaningful education (Biesta, Priestley, & Robinson, 2015). The promotion of teacher agency is about creating a collegial culture within a school ecosystem where innovation is encouraged (Priestley & Biesta, 2013). Models of teacher agency include that of social cognitive theory, distinguishing personal, proxy, and collective agency (Bandura,

2011). Agency in schools can be practised by teachers and/or communities (Eteläpelto, Vähäsantanen, Hökkä, & Paloniemi, 2013) and the 'teacher professional growth' model shows dynamic relations and characteristics of enactment and feedback or reflection (Clarke & Hollingsworth, 2002).

Essential characteristics of a model for integrating professional development and school reform from an agency perspective were identified by (Imants & Van der Wal, 2020) which include the active role of individuals, the non-linear dynamic character of the relationships; the complex multiple level work context, the process of professional development and school reform as events in a continuing cycle and the inclusion of the content of professional development and school reform. They conclude that the central role of teacher agency in professional development and school reform embodies interactive and multi-level dynamic interactions, including changes from individual to team, school and above school level. The model developed presents the teacher as an actor, dynamic relationships, treating professional development and school reform as inherently contextualized, including multiple levels, content of professional development and reform as variables considering outcomes as parts of a continuing cycle Imants & Van der Wal (2020).

Research Method

Research design

Following the model of a reflective teaching cycle (Smith 2001), a collaborative action research design was adopted in this study (Murray 2015; Yin and Buck 2019). Collaborative action research was adopted as it guaranteed that the teachers and teacher educators created and developed their practice through reflective teaching cycles (Butler et al. 2013), with the cycles including planning, teaching and reflecting. The reflective

process is situated in the context of dialogue or reflective conversations between the teacher and teacher educators, or critical friend (Costello et al. 2015). This concept of dialogical action research was of particular interest to this study and enacted throughout the action research cycles.

Figure 1 illustrates the research design, the three academic years enactment and the action research cycles. The project commenced with a pilot phase 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 from teachers and positive feedback from the pilot schools, 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 Numeracy Deep Dive would be continued with the PDST supporting teachers who elected to participate, and consultation with the Inspectorate would also continue, the actors in the action research. The first Action Research (AR) cycle commenced in AY2017/18 with six schools, where the research outputs informed the development of the second cycle in AY2018/19 involving 10 schools.

Figure 1. Collaborative action research cycles stages and cycles based on Butler et al. (2013)

Research Participants

The project was operationalised by the Professional Development Service for Teachers (PDST) and the Department of Education and Skills Inspectorate, who are responsible for the evaluation of primary and post-primary schools. The PDST are a national body, established in 2010 by the Department of Education and Skills (DES), who support in-

service teacher professional learning and evidence-based practice, placing specific emphasis on curriculum and pedagogy, learning and teaching methodologies (PDST, 2015).

School and teacher collaborative cultures take time to develop, requiring trust and mutual understanding (Lytle and Fecho 1991). Derived from day-to-day interaction as well as long-term relationships of participants, was decided that pairing the disciplines of Mathematics with another subject would be best in the initial NDD rollout, until a whole school community and collaborative culture was established. NDD was therefore designed to involve pairs of post-primary teachers, one teacher who teaches mathematics and another teacher of a carrier subject. The involvement of the mathematics and with another teacher, from a different discipline, was decided for this project evidenced by the work of Dweck (2014), Sandholtz (2000) and Jang (2006).

The research participants in this collaborative action research study included three cohorts: 1) the mathematics and carrier-subject teachers, 2) the PDST teacher educators who led Numeracy Deep Dive workshops, supporting teachers throughout the three academic years, and 3) an external university-based teacher educator who again acted as critical friend to the PDST teacher educators (Fletcher et al. 2016).

Professional Learning Model

The model adopted for the effective design of professional development is that of Loucks-Horsley et al. (2009) and this model has four strategies for professional learning. The first strategy involves immersion in content, standards and research; the second involves examining teaching and learning; the third is aligning and implementing curriculum, and the fourth strategy the professional development structure (Loucks-Horsley et al., 2009).

Figure 2. Conceptual framework of the professional learning model for the NDD project adapted from Loucks-Horsley et al. (2009)

In regard to the first strategy involving immersion in content, standards and research – the formation of collaborative partnerships between teachers, university researchers and curriculum designers are involved. Collaborative networks provide opportunities for professional learning around topics negotiated and agreed upon by the group, thus ensuring common goals. The Numeracy Deep Dive network consisted of a university teacher educator, PDST, DES Teacher Education Section (TES) and the variety of carrier subject as well as the Mathematics teachers. School leadership was critical in establishing an immersion of inquiry and problem solving and course/topic development. Multiple cross-curricular possibilities and overlap between subject specific learning outcomes were sourced and encouraged.

In the Loucks-Horsley et al. (2009) model the second strategy involves examining teaching and learning, and in this project an action research methodology was adopted. Action research is an appropriate methodology for supporting educational reform (Somekh & Zeichner, 2009). A series of Deep Dive meetings and school visits was conducted by the PDST to support the pairing of teachers through the action research cycle and thus refining the planning, implementation and evaluation of the work. The Inspector assigned to TES also supported the teachers. Five meetings with the teacher pairings were facilitated between November 2018 and May 2019, Table 1. One of these was a full-day six-hour workshop, 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 concerned with developing

collaborative professional dialogue between teachers and the PDST advisor assigned to support them. The teachers were encouraged to identify their roles and work implications, including key dates regarding the collaboration and implementation while also ascertaining potential dates of support visits by advisors to the participating schools and the nature of engagement with the PDST advisor.

Table 1. Overview of support meeting between PDST Advisors and teachers

Meeting	**Duration**	**Topic**
Meeting 1	6hrs	Introduction to NDD, digital planning, STEM agenda and numeracy.
Meeting 2	2hrs 30mins	Conversations between teachers on curriculum topic, planning schemes of work collectively.
Meeting 3	2hrs 30mins	Lesson planning, resource design.
Meeting 4	2hrs 30mins	Resource design, student progress.
Meeting 5	2hrs 30mins	Showcasing NDD outcomes from academic year.

The third strategy is aligning and implementing curriculum – the PDST and the Department provided teachers with resources and experiences which included numeracy-based learning opportunities and examples of numeracy investigations and assessment tasks in both subjects. In all cases, learning outcomes and related learning intentions provided the detail of how pair of teachers envisaged student learning progressing in a manner that was authentic and allowed students to take ownership of their work. The conversations between teachers and PDST visits assisted teachers as they created new windows of opportunity to plan, enabling them to sequence work to fit within an agreed timeframe. In some cases teachers switched classes with colleagues to facilitate team-teaching and or amended curricular plans.

The fourth strategy is a professional development structure, an emphasis on study groups and networks for curriculum implementation in that teachers develop and implement units of work that target numeracy demands of the diverse curriculum areas from which they were drawn. This overall approach provides long-term provision,

teacher and subject collaboration to champion numeracy and develop learning. In order to achieve this, teachers often communicated electronically using WhatsApp and email for example, as face-to-face discussion in the staffroom was not always possible. 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 noted the benefits of this approach especially if they also taught some of the same student cohort within the carrier subject. In some cases, teachers found that having an already established relationship with their colleague was useful and led to a working relationship embedded in trust which served to facilitate collaboration and foster creativity.

Data Collection

There were three forms of data collection: reflections by teachers, NDD teacher focus group, and critical friend conversations with PDST advisors in the analysis of the professional learning model and the NDD project.

Teacher reflections were gathered during and at the end of the project documenting their collaboration and outcomes. The teacher groups were invited to submit written journals on their perceptions and observations during the NDD. A template was provided to each school or pair of teachers, so the teachers collectively completed this providing an overview of their NDD experience.

The NDD teacher focus groups were conducted at the last meeting, meeting 5, of the NDD project. Powell and Single (1996) define a focus group as “a group of individuals selected and assembled by researchers to discuss and comment on, from personal experience, the topic that is the subject of the research” (p. 499). This qualitative method of data collection was conducted by the University teacher educator with participant teachers in a semi-structured discussion, designed to generate a rich understanding of a topic. The experiences of the NDD teachers were explored in

relation to a set of predetermined questions, the content unique to the study. Focus groups are an applied research method intended to gain in-depth information into the feelings, attitudes, and perspectives of participants, providing insights into why participants believe as they do and how they arrived at these beliefs.

The critical friend conversations were guided by Kitchen and Steven (2008) and focused their dialogical reflections on the two research questions. Furthermore, following the approach taken by Fletcher et al. (2016), the teacher educators and critical friend engaged in regular reflective dialogues at the analysis and write-up phase of the research cycle, critically assessing and feeding back strengths and limitations of the analysis.

Data Analysis

The qualitative content analysis approach was adopted in this study (Heish and Shannon 2005). A research method for making replicable and valid inferences from data to their context, providing knowledge and insights along with a practical guide to action (Krippendorff 1980). A deductive approach was utilised as it is based on existing theory as it moves from the general to specific (Catanzaro 1988). The content analysis involved defining codes before, from theory, and during data analysis from the multiple voices (which was particularly important for the NDD teacher focus group interviews). Through this process, themes and sub-themes were constructed. The Inspector assigned to TES and University teacher educator met several times to discuss and reach a consensus regarding the theoretically informed constructed themes and sub-themes and consulting on how best to present the research data.

In analysing the first RQ, regarding what pedagogical approaches were adopted by teachers in the cross curricular integration of numeracy, it was decided to present two samples pertaining to the second AR cycle.

In answering the second RQ, on how well the professional development approach supported teachers' learning - observing the work of Imants & Van der Wal (2020) and the professional development opportunities for teacher agency, the data was analysed in regard to their four themes: individual practice, outcomes, perceived work context and school reform. Data was analysed under themes and the following section presents the findings under each theme, with chosen teacher quotations providing the reader with the teacher voice, followed by a discussion.

Findings

The research findings, and sub-themes emerging from the data analysis, are structured around the study's two research questions. Supportive data is provided from teacher reflections (T1_reflection) and teacher focus groups (T_focusgrp) and dialogical reflections with the study's critical friend (TE_dialogic).

RQ1: What pedagogical approaches were adopted by teachers in the cross curricular integration of numeracy?

The project involves teachers identifying and agreeing the material to be explored and in creating authentic contexts to facilitate its exploration. Multiple cross-curricular possibilities and affording adequate overlap between the learning outcomes on the mathematics specification and those of the identified carrier subject was the primary rationale for teachers choosing the topics within their subjects. 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" (T1_reflection_S8). 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 participant teachers 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).

In AY2018/19, there was an initial involvement of ten schools who elected to progress work on NDD. One school dropped out of the project after this juncture and another school due to timetabling constraints withdrew. The nature and range of collaboration of those schools who participated is illustrated in Table 2.

Table 2. Participant schools in AY2018/19

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,GeoGebra, Worksheets,Video	2nd	3	3
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 Worksheet for 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)

A range of pedagogical approaches were used to engage students as they developed numerical skills in a manner where they made links between mathematics and the carrier subjects. Approaches were varied and independent of the carrier subject.

Examples included inquiry-based learning, team-teaching, classroom debates, peer assessment, problem solving worksheets and technology adoption such as GeoGebra and 3D (scaled) model making to visualise mathematical concepts and two examples are presented.

In School 5 AY2018/19 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" (T1_reflection_S5).

Figure 3. Poster presentation from School 5

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 mathematics class then used the data in the first week after Easter holidays (1st-3rd May), and brought their findings back to the science laboratory

to discuss and report in a final single Science class (May 7th). In collecting the data and graphing the teachers provided a minion worksheet for plotting co-ordinates and the topic was covered in the four mathematics and three science classes.

The students unknown to themselves, discovered they would get data easier to interpret if they changed one variable only i.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” (T2_reflection_S5). This project was deemed a success as students applied their mathematical knowledge into Science lessons seamlessly, Figure 3. It was noted that engagement between teachers from different subject departments also increased, which contributed to overall school improvement, strengthened links between the Mathematics Department and other disciplines and introduced common mathematical language.

An inquiry-based learning approach was adopted by School 4 where the Mathematics department and the Art department collaborated, Figure 4. 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" (T1_reflection_S4). The Art class was asked to create the Graduation Ceremony backdrop. 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 were expected to be able to translate between scale lengths and actual lengths on drawings, photographs, and models and draw both sketched and diagrams to scale.

Figure 4. Graduation ceremony artefact developed in Mathematics and Art, School 4

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 Mathematics 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" (T2_reflection_S4).

Overall participating teachers commented that students had an increased understanding, motivation to learn and retention of concepts explored (Furrer, Skinner, & Pitzer, 2014; Hargreaves, 2000). Indeed, in the focus group teachers explained how non-participant students, who were aware of other classes where the NDD project was being employed, sought to know why they could not collect data in science class and use it in mathematics, asking their chemistry teacher "to get onto the other teachers and tell them they have to do this" (T5_focusgrp). 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, 2005). Indicative of the improved learning experiences for students was the increased attendance levels in classes. This phenomenon was the case in School 4 where attendance was often problematic with other cohorts of students. These observations correlate with the work of the great teacher of mathematics, Pólya, who commented on the art of teaching which was providing students with an opportunity to discover things by themselves (Pólya, 1981). It is also 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, for example, as the students engaged in activities such as the creation of audio files in OneNote, written explanations of graphs, group discussion and the presentation of work to peers.

RQ2: How well did this professional development approach support teachers' learning?

The effectiveness of the teacher agency, the activity resulting from individual practice and perceived work context (Biesta et al., 2015), in NDD professional development is analysed by identifying features that were critical to its success. Imants and Van De Wal (2020) emphasise the dynamic relationship between individual teacher agentic practice and the structural component of teachers' work environment as context for teacher practice is central to their model. The model is a tool to identify complexities in

professional development and reform processes before, during and after projects, from a practical and policy perspective and is used as a frame of reference. Teacher participant reflections of the NDD project were gathered and analysed in regard to the four themes: individual practice, outcomes, perceived work context and school reform (Imants & Van der Wal, 2020).

Individual Practice

The participant teachers' individual practice and behaviour was characterised by them proactively taking initiative to participate in the NDD project. Reflections by the teachers based on the impact of the co-professional planning with which they engaged are consistent with the statements of highly effective practice from the Department of Education and Skills, Looking at Our School 2016 A Quality Framework for Post-Primary Schools (DES, 2016a). Where the statements state that teachers create an inclusive, orderly, student-centred learning environment based on mutual respect, affirmation and trust, in which students regulate and monitor their own behaviour; and secondly that teachers demonstrate confidence and proficiency in the skills and knowledge of their subject areas, and can link these to other disciplines across and beyond the curriculum. In addition to bringing their practice within the range of those regarded as highly effective, teachers remarked to have learned new techniques and methodologies to enhance students learning (this was often evidenced by their adoption of GeoGebra, SolidWorks or other software applications.) Teachers reflected the collegial support when planning or dealing with difficult situations and receiving validation from students regarding the positive impact their practice was having on learning. Some teacher responses indicated that the NDD ultimately saved time when teaching a topic, thus allowing for other areas to be further explored in terms of teaching.

Outcomes

The organisation outcomes were evident in the reflections by the teacher participants, as many explained it was the first occasion that they conducted planning in a structured and collaborative way. The effort 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. All 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" (T1_reflection_S6). 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" (T2_reflection_S3). 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.

To realise the potential of the nature of an optimal collaboration between, mathematics and carrier subject teachers, the following processes were deemed as outcomes by the participant teachers, such as examining the areas of cross-over between both specifications; sharing teaching timetables with one's colleague; exercising qualities of patience and honesty; maintaining open pathways of planning and communication (some planning was carried out up to four months in advance while other plans were made in anticipation of seasonal growth at Springtime within a habitat); and acknowledging evidence from formative assessment practices so that if unexpected issues arise e.g. the concept of non-integers within the mathematics class, plans were adapted in-running to allow for further opportunities to deepen student

learning. Hence, this method of assessment served to highlight gaps in student learning beyond the scope of the initial learning intentions within a planned Unit of Learning.

Perceived Work Context

The Irish curriculum overall has moved towards an emphasis on so-called key skills: "[the] embedding of key skills in the curriculum will thus involve building on current practice but it also involves increasing attention to the skills and their potential for actively engaging learners" (NCCA, 2009). It was evident from the variety of projects that the eight Junior Cycle key skills were being addressed through these collaborative projects (NCCA, 2009).

Figure 5. Junior Cycle Key Skills (NCCA 2009)

A 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 development of 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. Skill integration observations align with research findings in Australia by Geiger and others (Geiger, 2014; Goos, Dole, & Geiger, 2011a; Morony et al., 2004).

As most teachers indicated that the project ultimately saved time when teaching a topic, others indicated that the principal challenge was the time constraint regarding attempted planning. Responses indicated that it would have been more beneficial if

more time was made available to consider the practicalities involved in aligning schemes of work between subjects. However, participation in the NDD 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.

Teacher participants highlighted the importance of good relationships with colleagues. 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 meeting. 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 planned to present their findings at national teacher professional development and research forums.

School Reform

The project experience of the participant teachers is aligned with The Framework for Junior Cycle 2015 reflecting on the role of the teacher and the nature of the teacher-student relationship - reflecting on how learning is progressing and deciding on next steps to ensure deeper learning and successful learning outcomes. It was recommended that a range of assessment activities may be used to achieve this goal and a shift from focusing mainly on summative judgements to engaging in ongoing activities that can be used to support the next stages of learning. In the design of the NDD project it was proposed that that within lessons there was a greater opportunity to enable students acquire and apply their knowledge and learning and to use information in creative ways and that there was greater use of other resources, including ICT and practical materials. Both of these were deemed by participants to be commonplace in the NDD project. One teacher stated “This project has shown me that small changes to lessons can have a huge

impact on learning and attitude to learning with students" (T1_reflection_S4). Student engagement in teaching and learning allowed the teachers to see how the experience was preparing their students for forthcoming classroom based assessments (CBAs), a new concept in the Irish education system. As there are much curricular reform occurring in Irish education and the participant teachers were aware of how professional development could benefit them in the aligning to the upcoming changes.

Conclusions

The curriculum does not become real until it is enacted in the interactions which take place between the teacher and student (Crooks & McKernan, 1984). There is an underlying message which is that this requires very active engagement by the teaching profession and is about developing practices to be adopted and encouraging curriculum as social practice and the Numeracy Deep Dive Project resulted in authentic, rigorous engagement between multiple teachers, cross-discipline, collaboratively engaging with the curriculum. The primary challenge for teachers using this approach was time for the planning a combined 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 expand their range of collaborative experience with their colleagues. Considering evidence gathered regarding challenges encountered the implementation of future NDD projects will include an emphasis on the use of digital tools and a more considered pace.

We acknowledge that there are limitations to this study in terms of the uniqueness of the Irish educational system and the diversity of subject discipline available. We recognize that conducting the study in a different school with different students could result in different outcomes due to individual differences and preferences. Despite these limitations, the findings can be used to highlight the benefits

of a teacher professional development project to develop numeracy in students in a cross curricular manner. Due to the limited exposure to numeracy in initial teacher education programmes it is imperative that teacher professional development facilitates numerical development in a collaborative approach. At the time of writing the Department of Education and Skills have invited submissions to a revised Literacy and Numeracy Strategy. There is the necessity for all students to be numerate upon leaving the post-primary education is critical for them to contribute fully in society.

Statements on conflict of interest

There are no conflicts of interest to declare with this research.

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