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Problematizing Spatial Literacy within the School Curriculum

Contemporary research is considering new forms of literacy that extend beyond the skills required to process alphanumeric data. The skills involved in visualising, reasoning, and communicating about 2D and 3D spatial information are commonly referred to as 'Spatial Literacy'. Research has highlighted a positive relationship between Spatial Literacy and achievement across a diverse range of subject areas. Internationally, researchers have observed that students often have underdeveloped levels of Spatial Literacy on matriculation to third-level courses, particularly in the STEM area. In an attempt to better understand the potential reasons for this, this paper endeavours to unpack the complex nature of Spatial Literacy, its definition and associated metrics. Concerns are raised about the Spatial Literacy levels of Irish students based on international metrics and benchmarking against other jurisdictions. This paper seeks to problematize Spatial Literacy within the Irish educational context with a particular focus on dominant curriculum ideologies and education policy discourse.

Keywords: spatial literacy; visualisation; educational policy; school curriculum

Introduction

Definitions of what it means to be literate are often varied, divergent and unclear (UCLES 2013). Understandings of what it means to be literate or illiterate are influenced by; academic research, institutional agendas, national context, standardised international tests, cultural values and personal experiences (UNESCO 2006). Traditionally, the word *literate* meant to be "familiar with literature" or more generally, "well educated, learned" (UNESCO 2006). With the rapid development of the technological world in which all sorts of digital and multimodal tools are available, students can now engage in multi-semiotic reasoning and communication. This has forced researchers, curriculum developers and teachers to reappraise the nature and definition of *literacy* (Cervetti et al. 2010; Curtis 1978; Luna et al. 2000; Uhlig 1983). The autonomous model of literacy which was traditionally conceptualised as the skills associated with reading and writing using alphanumeric print based text is now contested by emerging views which take changing personal, social, cultural and historical factors into account (Street 2003).

Literacy as a concept has evolved; it is largely no longer viewed as a single entity, but rather as a combination of a number of different literacies (Bailey and Van Harken 2014; Cope and Kalantzis 2009). Discussions relating to *new literacies* involve; technologies and a heightened awareness of socioeconomic needs and cultural diversity (Cervetti et al. 2010; Luna et al. 2000; Carmody-Hagwood 2000). Examples of new literacies that extend beyond print based text include, inter alia; Digital Literacy (Buckingham 2015), Technology and Information Literacy (Anstey and Bull 2006; Moore 2011), Spatial Literacy (Moore-Russo et al. 2013), Music Literacy (Asmus Jr 2004), Dance Literacy (Risner and Anderson 2008), Play Literacy (Roskos and Christie 2001), and Health Literacy (Parker et al. 1995).

In 1958, UNESCO defined a literate person as somebody "who can, with understanding, both read and write a short simple statement on his or her everyday life" (UNESCO 2006). Definitions and understandings of literacy have broadened significantly over the past 50 years and now consider contextual and societal transformations. The Organisation for Economic Co-operation and Development (OECD) defines *literacy* as "the ability to understand and employ printed information in daily activities, at home, at work and in the community – to achieve one's goals, and to develop one's knowledge and potential" (OECD 2000, p.x). Printed information can be in the form of 'continuous texts' and 'non-continuous texts'(OECD 2006). The current UNESCO definition for literacy reflects this where it is considered, "a means of identification, understanding, interpretation, creation, and communication in an increasingly digital, text-mediated, information-rich and fast-changing world" (UNESCO 2017). For the purpose of this paper, this UNSECO (2017) definition of literacy has been adopted. It reflects a broad understanding of literacy to include constructs such as *Spatial Literacy*. However, it is worth noting that a broad conceptualisation of literacy is often challenged by a lack of effective tools for monitoring and evaluating levels of literacy across a spectrum of areas (Wagner 2008).

This paper firstly explores the growing international interest in defining and measuring different literacies which often include *Spatial Literacy*. The treatment of Spatial Literacy in Irish secondary schools is then analysed through the lenses of education policy documents and data yielded by international metrics of literacy. Finally, the paper seeks to problematise Spatial Literacy within the Irish educational context with a particular focus on dominant curriculum ideologies and educational policy discourse.

International Metrics of 'Literacy'

Since 2000, the OECD has administered a triennial international survey known as the Programme for International Student Assessment (PISA) that focuses on core school subjects of science, reading and mathematics. The instrument aims to evaluate and compare education systems throughout the world by comparing skills and knowledge of 15-year-old students (OECD 2017b). The 2015 PISA assessment measured; Scientific Literacy, Reading Literacy, Mathematical Literacy and Financial Literacy. Each round of PISA assesses an “innovative domain”; in 2015 this was “collaborative problem solving” (OECD 2017a). Policy makers throughout the world use PISA scores to establish and compare the quality of different education systems, and to determine benchmarks for future improvement (OECD 2017a).

Since its establishment in 1958, the International Association for the Evaluation of Educational Achievement (IEA) has conducted over 30 comparative cross-national studies of educational achievement across a number of subjects and disciplines (IEA 2017; Mullis et al. 2004). Two of these studies that are frequently referenced in education policy documents are; Trends in International Mathematics and Science Study (TIMSS), and Progress in International Reading Literacy Study (PIRLS). In contrast to PISA, the TIMSS assessment does not explicitly measure any particular ‘literacy’, rather it measures students’ mastery of subjects (IEA 2017). PIRLS does explicitly measure ‘Reading Literacy’ where it is defined as “the ability to understand and use those written language forms required by society and/or valued by the individual. Readers can construct meaning from texts in a variety of forms. They read to learn, to participate in communities of readers in school and everyday life, and for enjoyment” (Mullis et al. 2015, p.12). TIMMS is administered every four years at both Grade 4 (10 years old) and Grade 8 (14 years old). PIRLS is administered once every five years to Grade 8 (14 year old) students only.

Defining Spatial Literacy

The modern world has become increasingly visual, digitised and data-rich. The integration of modern digital technologies into homes, schools, universities and workplaces means that people not only require the skills and knowledge to work with alphanumeric data but also spatial data (Hegarty et al. 2017; Moore-Russo et al. 2013; Utal and Cohen 2012). Spatial data can be represented in various digital and analogue forms including, inter alia; maps, diagrams, drawings, graphs, flowcharts, medical x-rays and scans, CAD (Computer Aided Design) models, and sketches. In order to work with these data, the skills involved in visualising, reasoning and communicating about two-dimensional (2-D) and three-dimensional (3-D) spatial information are necessary. Internationally, well-developed levels of Spatial Literacy are cited as predictors of success and engagement in STEM (Science, Technology, Engineering and Mathematics) courses at third-level (Gagnier and Fisher 2016; Lubinski 2010; Sorby et al. 2014;

Veurink and Sorby 2017; Wai et al. 2009), however, interventions are frequently required to address Spatial Literacy deficiencies at secondary school level (Julià and Antolì 2017) and upon matriculation to third-level courses (Lane and Sorby 2015; Utal and Cohen 2012; Utal et al. 2013). It has been frequently observed that females tend to struggle more than males on tests that measure some aspects of Spatial Literacy (Hoffman et al. 2011; Linn and Petersen 1985).

The 'Spatial Turn' as described by Montello et al. (2014) is an emergence of interest across many disciplines in space and spatiality and how these can help people to understand and interact with the natural, cultural and virtual worlds. Researchers are increasingly interested in the nature of spatial functioning (Newcombe and Shipley 2015), and examining how people interact with visual representations (Eilam and Ben-Peretz 2010) and spatial data (Shin et al. 2016). A number of terms that describe these cognitive processes are common in contemporary research literature (Avgerinou and Ericson 1997). These include, inter alia; 'Visual Literacy' (Ariga et al. 2016; Messaris 1994), 'Spatial Literacy' (Moore-Russo et al. 2013) and 'Graphicacy' (Baynes 2014). While all of these have subtle differences, they primarily involve skills in thinking about the physical and virtual world in which spatial information is present.

A 2006 report from the USA, titled *'Learning to Think Spatially'*, concluded that schools cannot meet their responsibility for equipping the next generation of students for life and work in the 21st century without explicit attention to the development of spatial thinking skills for all students (NRC 2006). This has since been supported by numerous researchers including, inter alia; Shin et al. (2016), Bailey and Harkin (2014) and Moore-Russo et al. (2013). The current international interest in Spatial Literacy is reflected in the formation of a number of research clusters throughout the world. One example of this is the S*patial Intelligence and Learning Center* (SILC) in the USA which is funded by the National Science Foundation (SILC 2018).

A person who is considered to be *Spatially Literate* has developed appropriate levels of knowledge and skills that enable them to think, act and reason about the world in spatial ways (NRC 2006). Consensus is beginning to form around the multifaceted nature of Spatial Literacy, comprising broad sets of interconnected competencies that can be taught and learned. Moore-Russo et al. (2013) describe a spatially literate person as having the skills to; visualise spatial objects, reason about properties of and relationships between spatial objects, and communicate and receive information about spatial data. Similarly, the 'Learning to Think Spatially' report (NRC 2006, p.ix) describes the processes involved in working with spatial data as; “a constructive amalgam of three different elements: concepts of space, tools of representation, and processes of reasoning”. Space provides a framework in which data can be integrated and structured. Reasoning processes facilitate the interpretation, manipulation, synthesis and communication of information. For the purposes of this paper, the model of Spatial Literacy described by Moore-Russo et al. (2013) has been adopted where it is comprised of three fundamental domains; ‘Visualisation’, ‘Reasoning’ and ‘Communication’. The processes associated with each of these domains are described in Table 1.

Table 1. Processes associated with the domains of Spatial Literacy

Visualisation	Reasoning	Communication
The generation of mental images of 2D and 3D spatial objects Visualisation can take place without any reasoning or communication taking place Visualisation can extend beyond spatial geometry to include other forms of text Approaches to visualisation can vary where some individuals focus on discreet elements, while others might view the overall appearance	Organising, comparing and analysing spatial concepts and relationships Forming conclusions and making judgements from a given set of premises Reasoning can take place without any visualization or communication taking place – visual images do not always need to be generated nor does information always need to be exchanged with others	Exchange of information through interaction with others Resources used to communicate information about spatial concepts include; language, written inscriptions, sketches, computer models, gestures etc. Communication does not necessarily involve the construction of visual images or reasoning

Spatial Literacy is “not limited to graphic representations of the visual world” (NRC 2006, p.36). Spatial representations can be internalised in the ‘mind’s eye’ (Fish 1990), or externalised through different forms such as; language, mathematical notation, written inscriptions, physical gestures, and so on (Bailey and Van Harken 2014; Grek 2008; NRC 2006). Moore-Russo et al. (2013) explain that spatial problems can often be solved and communicated without the need to visualise and reason through images. In fact, they claim that flawed vocabulary can hinder people in grasping basic spatial concepts when communicated through text. This is also supported by Gentner et al. (2013) where they describe the importance of spatial language in supporting spatial cognition.

The processes described in Table 1 highlight the broad nature of Spatial Literacy and this creates an educational challenge around where in the school curricula the teaching and development of Spatial

Literacy skills best sits/fits, especially when it is considered that the development of Spatial Literacy skills begins at infancy and continues throughout adulthood (Newcombe 2017). It is becoming increasingly evident across multiple jurisdictions that Spatial Literacy is not tied to any one subject area and that it has a broad educational value. Contemporary research highlights the importance of Spatial Literacy in subject areas beyond STEM including, inter alia; Geography (Metoyer and Bednarz 2017), English (Black 2005), Music (Hetland 2000) and Coding (Francis et al. 2016). However, Bednarz and Kemp (2011, p.22) argue that "there is a need for attention to the ways that Spatial Literacy can be measured and evaluated".

Measuring Spatial Literacy

There are no international standards that explicitly measure or evaluate all three domains of 'Spatial Literacy' (Bednarz and Kemp 2011; Moore-Russo et al. 2013). However, both the TIMSS and PISA metrics have content that closely aligns with the 'Visualisation' and 'Reasoning' domains. In the Mathematics content domain for TIMSS, there are sections at both fourth and eighth grade that assess student understanding of Geometry with particular reference to their knowledge of points, lines, and angles; and 2-D and 3-D shapes. There are also sections relating to 'data interpretation' that assess students ability to read, interpret and represent data from tables, pictographs, bar graphs, line graphs and pie charts (Mullis and Martin 2013).

In PISA, the 'Mathematical Literacy' framework includes a section called 'Space and Shape' – "Mathematical Literacy in the area of space and shape involves a range of activities such as understanding perspective (for example in paintings), creating and reading maps, transforming shapes with and without technology, interpreting views of three-dimensional scenes from various perspectives and constructing representations of shapes" (OECD 2017a, p.74).While not explicitly referred to as 'Spatial Literacy', the language used to describe the 'Space and Shape' section closely aligns with the Moore-Russo et al. (2013) definition for Spatial Literacy described previously. Within the PISA framework, geometry is described as an essential foundation for 'Space and Shape' but it is also highlighted that it extends to other mathematical areas such as; spatial visualisation, measurement and algebra. Furthermore, the OECD describes manipulation and interpretation tools such as dynamic geometry software and Global Positioning Software (GPS) as being important for 'Space and Shape'.

Beyond PISA and TIMSS, there are no other major standardised international tests commonly referred to within education policy documents that explicitly measure the skills involved in working with spatial concepts. However, several research tests have been designed and employed across numerous disciplines that help researchers in better understanding specific aspects of Spatial Literacy. These include, inter alia; advanced tests of cognitive function during spatial reasoning tasks using functional magnetic resonance imaging (fMRI) (Knauff et al. 2002), and the use of Electroencephalography (EEG) to examine cognitive processing during graphical problem solving episodes (Delahunty et al. 2017). Paper based tests that measure visualisation and reasoning domains of Spatial Literacy include, inter alia; the Purdue Spatial Visualisation Test of Rotations (PSVT:R) (Guay 1977), the Mental Cutting Test (MCT) (CEEB 1939), the Mental Rotation Test (MRT) (Vandenberg and Kuse 1978), and the Differential Aptitude Test of Space Relations (DAT:SR) (Pearson 1996).

Spatial Literacy and Irish Educational Policy Rhetoric

In the absence of international standards that explicitly appraise levels of Spatial Literacy, Irish educational policy has been increasingly influenced by PISA and TIMSS. For example, the Action Plan for Education, 2016 – 2019, sets out a vision for Ireland that includes a number of high level goals and ambitions that are designed to help the Irish Education and Training System to "become the best in Europe over the next decade" (DES 2016a, p.1). There are several measures and targets within this strategic plan associated with Literacy, including increasing PISA performance scores in reading, science and mathematics. However, Spatial Literacy is not explicitly addressed within this document and descriptions of 'literacy' fail to extend beyond the traditional skills associated with reading, writing and arithmetic, with the exception of presenting specific objectives to promote 'emotional literacy' (DES 2016a) which is seen as within the remit of the National Taskforce on Youth Mental Health. The National Strategy to Improve Literacy and Numeracy among Children and Young People (2011-2020) (DES 2011) does refer to 'literacy' and 'numeracy' as "much more than reading, writing and arithmetic" (DES 2011, p.8). The actions associated with the assessment and evaluation of literacy and numeracy within this strategy again include specific reference to participating in international tests such as PISA, TIMMS and PIRLS in order to benchmark against international standards. Furthermore, the second level subjects of English, Irish (native language), Mathematics and Science are frequently referred to as having critical importance in achieving desired targets. These strategic policy documents highlight the contested space that Spatial Literacy must fight for recognition within Irish educational policy. There exists an espoused recognition of broader conceptualisations of literacy but this is constrained by neoliberal efforts to meet international performativity metrics and standards. This dichotomy between the competing desires to embrace broader conceptions of literacy and to respond to the performativity pressures of international tests has resulted in the reality that literacy continues to be narrowly defined within Irish educational discourse.

Increasingly, the rhetoric associated with a broad conceptualisation of literacy appears to be losing out to a neoliberal agenda in Irish policy, where 'globalisation' (Lawn 2013), 'governance by numbers' (Ball 2015; Ozga 2008), and the need to excel in international metrics has militated against the realisation of a reality where broader elements of literacy, including Spatial Literacy skills, are valued. For example, the National Skills Strategy 2025 (DES 2016b) in describing 'literacy' refers primarily to those elements that are measured by PIRLS, TIMSS and PISA. Furthermore, the recently released curriculum policy document 'A Framework for Junior Cycle' (NCCA 2015) lists 'being literate' as one of eight key skills that students should develop and specifically references 'enjoyment of words', 'reading for enjoyment', and developing the 'spoken language'. The subjects of English, Irish and Mathematics are afforded more hours in this policy as they are described as being important in "supporting literacy and numeracy" (NCCA 2015, p.20). The growing 'fetishisation' (Lewis 2017, p.287) for transforming different qualities and skills into metrics of school and student performance (Espeland and Stevens 1998) where "only the measurable matters" (Lynch 2006, p.7) appears to be not only resulting in a narrow, lived definition of literacy, that excludes broader elements such as Spatial Literacy, but are also restricting the control of literacy to a few specified subject disciplines, arguably further elevating the status of these subjects within a hierarchy of school disciplines (Lynch and McGarr 2014).

Acknowledging the dominance of international metrics and the declared targets within Irish policy to increase student performance scores, further consideration must be given to the current treatment and performance of students regarding Spatial Literacy within Irish education.

Spatial Literacy Performance Indicators for Ireland

Based on the review of Irish educational policy in the previous section, it is unsurprising that the specific term 'Spatial Literacy' is not commonly referred to within the Irish research community. Instead, reference is made to terms such as; ‘spatial skills’ (Duffy et al. 2015), ‘spatial ability’ (Bowe et al. 2016), ‘spatial cognition’ (Buckley et al. 2017), and ‘visuo-spatial skills’ (Gaughran 2002). These terms have discreet definitions associated with them, however, they all have some commonalities with the three domains of ‘Spatial Literacy’ (Moore-Russo et al. 2013).

Clusters of researchers are beginning to form in Ireland with an interest in alleviating the difficulties that are faced when students enter third-level courses with under-developed levels of Spatial Literacy. In 2015, the National Spatial Skills Research Network (NSSRN) was established by a group of researchers from three Irish universities (Bowe et al. 2016). In a recent publication by some of these researchers (Bowe et al. 2016), it was concluded that first year students in secondary schools potentially have an “underdeveloped cognitive faculty of spatial ability” (p.5) and that specific interventions may be warranted to address these deficiencies. The test instruments used in the study were paper based instruments through which ‘visualisation’ and ‘reasoning’ domains of Spatial Literacy were measured.

Irish students have consistently performed significantly poorer in the ‘Space and Shape’ section of PISA (Fig. 1). Females and males score statistically significantly above the OECD average in three of the four sections of the Mathematical Literacy domain in PISA, however the performance of males in ‘Space and Shape’ is rated as ‘similar to OECD average’, and the performance of females in ‘Space and Shape’ is ‘below OECD average’ (Perkins and Shiel 2016; Shiel and Kelleher 2017). In their comprehensive analysis of recent PISA results, the Irish Educational Research Centre (ERC) which is a statutory body established by the Irish Government points out that this poor performance is a cause for concern (Perkins and Shiel 2016; Shiel and Kelleher 2017). Further concerns have been expressed about the wide gender gap that exists between males and females where females score an average of 25 points lower than their male counterparts (Fig. 2) (Close and Shiel 2009).

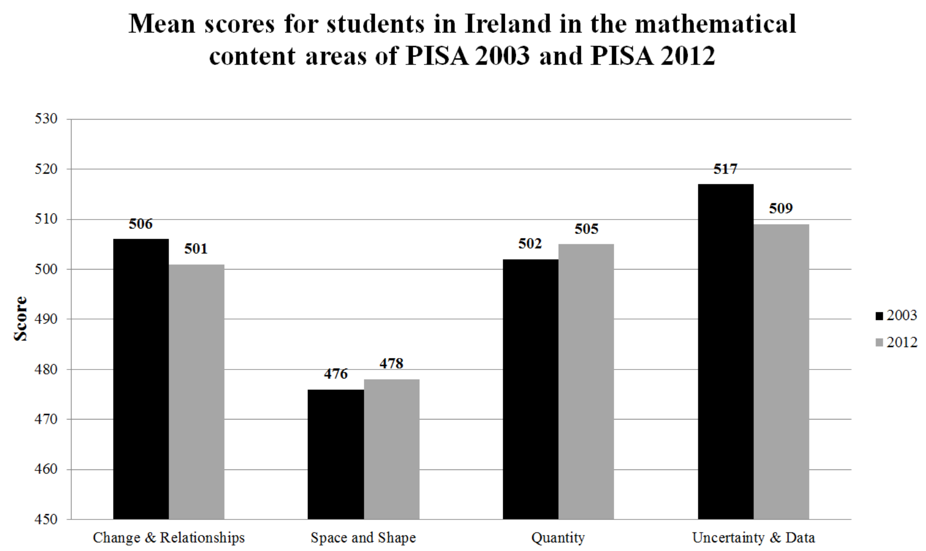

Fig. 1 Mean scores for students in Ireland in the mathematical content areas of PISA 2003 and PISA 2012

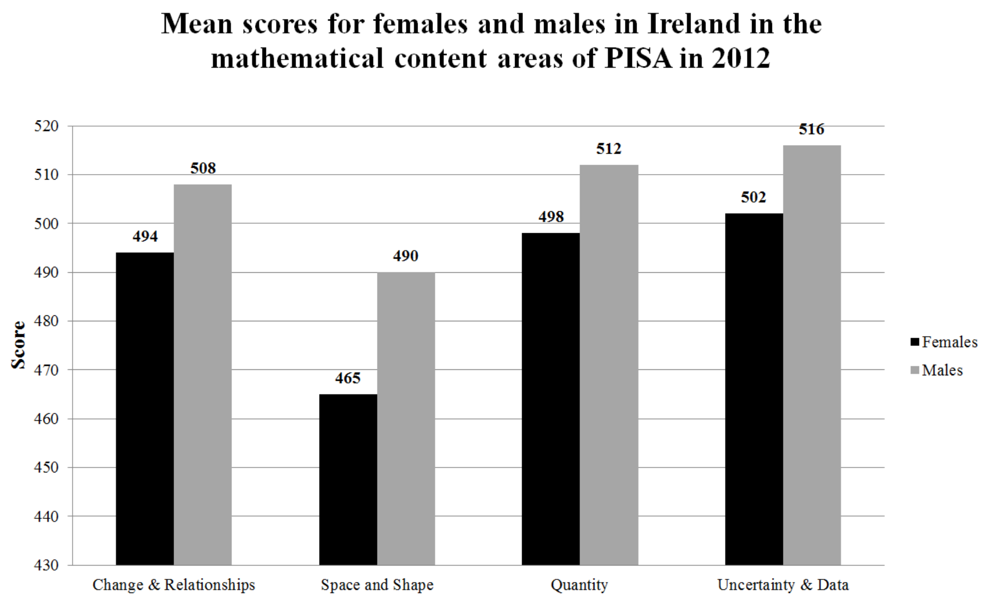

Fig. 2 Mean scores for females and males in Ireland in the mathematical content areas of PISA 2012

Further reports published by the ERC have highlighted that some mismatches exist between the national curriculum for Mathematics and what is measured in the Mathematical Literacy section of PISA (Close and Shiel 2009; Perkins and Shiel 2016; Shiel et al. 2006). The under-representation of females in Design and Technology subjects that expose students to practical application of spatial relations has also been highlighted by the ERC as a potential factor in the poor performance of females. Shiel et al. (2016) maintain that the poor performance in 'Space and Shape' in general may be due to underdeveloped visualisation and spatial reasoning skills. In summary, the PISA instrument has highlighted that Irish students underperform in the 'Space and Shape' element of Mathematical Literacy, but perform well in the other three domains that primarily involve numerical concepts. Other developed countries that have scored statistically significantly below the OECD average in 'Space and Shape' include, inter alia; the United Kingdom, Sweden, and the United States.

The performance of males and females in Ireland in TIMSS 2015 highlights similar trends to the performance in PISA. Clerkin et al. (2016) describe how items dealing with 'Geometric Shapes and Measures' (at Grade 4) and 'Geometry' (at Grade 8) posed difficulties for both genders. The performance in the Mathematics content domains for TIMSS 2015 are shown for grade 4 and grade 8 in Fig. 3 and Fig. 4 respectively. The performance in 'Geometric Shapes and Measures' at grade 4, and 'Algebra' and 'Geometry' at Grade 8 were considered to be a 'relative weaknesses' by Clerkin et al. (2016). In contrast, the performance in 'Number' at Grade 4, and the performance in both 'Number' and 'Data & Chance' at Grade 8 were considered to be a 'relative strength'. The performance in 'Algebra' at Grade 8 is similar to 'Geometry'. These similar scores support the view of the OECD (2017a) where they consider the cognitive skills involved in the study of both 'Algebra' and 'Space and Shape' as being similar. Recent research in the USA (Beilcock et al. 2010) has examined the relationship between levels of fear and anxiety about doing mathematics and the performance of females in mathematics tests. This should also be considered when interpreting the lower performance levels of females in tests such as TIMMS and PISA.

Fig. 3 Mean scores for grade 4 females and males in Ireland in the mathematical content areas of TIMSS 2015

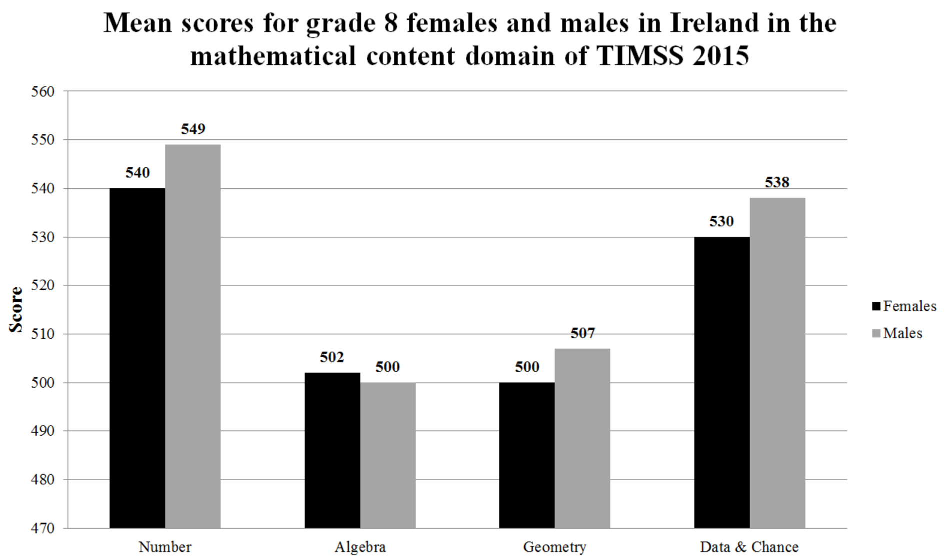

Fig. 4 Mean scores for grade 8 females and males in Ireland in the mathematical content areas of TIMSS 2015

The TIMSS Framework uses four benchmarks at which the performances of different countries can be compared. In TIMSS 2015 these benchmarks were; Low (scoring at least 400), Intermediate (scoring at least 475), High (scoring at least 550) and Advanced (scoring at least 625) (Martin et al. 2016). Each benchmark has associated indicative qualities. The performance of both genders in 'Geometric Shapes and Measures' at Grade 4 in Ireland was below 550 and therefore classified as 'Intermediate'. This means that pupils typically can "relate two- and three-dimensional shapes, and identify and draw shapes with simple properties". The higher 'Advanced' benchmark at Grade 4, for example, indicates that pupils typically can "apply knowledge of a range of two and three-dimensional shapes in a variety of situations". The performance of both genders in the mathematical content domain at Grade 8 in Ireland was also below 550 and therefore classified as 'Intermediate'. In relation to 'Geometry', this means that pupils typically can "show some knowledge of linear expressions and two and three-dimensional shapes". In contrast, the indicative skills at the 'Advanced' benchmark for Geometry describe how pupils typically can "use their knowledge of geometric figures to solve a wide range of problems about area" (Clerkin et al. 2016).

Moving away from PISA and TIMSS, other research has highlighted that Irish students struggle in tests that measure different aspects of Spatial Literacy and that skill levels are below standard in comparison to other egalitarian countries (Bowe et al. 2016; Duffy et al. 2015; Lane et al. 2012; Lippa et al. 2010). Much of the current research that examines aspects of Spatial Literacy in Ireland attempts to address poor spatial visualization and reasoning skills on matriculation to third level STEM courses. Duffy et al. (2015) examined the effect of a special spatial skills intervention (Sorby 2011) with first year science and engineering students. Lane et al. (2015) conducted similar research with first year undergraduate pre-service technology teachers. Both research studies describe how students' spatial visualisation and reasoning skills improved significantly after specific instruction.

The vision of the Irish government is for the entire education and training system to become the best in Europe by 2026 (DES 2016a). Furthermore, it is envisaged that the Irish school system will become an international leader in STEM education (DES 2017). The national policy documents referred to earlier describe how these ambitious targets will be met through performance in international tests such as PISA, TIMSS and PIRLS. The emphasis on performance in these tests is having an impact on the education system as a whole. Minimum entry requirements to most STEM university degree programmes in Ireland solely specify the study of Mathematics as a minimum requirement (IUA 2012; McGarr and Lynch 2015). Extra credit is awarded to students who achieve a grade D or higher in Mathematics in the summative exams at the end of secondary school. Hyland (2011) highlights that this may be adverse as it has a considerable "backwash effect" (p.4) on teaching and learning where the terminal examination that dictates college entry is the most important part of school. The national policy documents clearly highlight English, Irish, Mathematics and Science as important subjects in Irish secondary schools. Despite having been broadly defined in the 'National Strategy to Improve Literacy and Numeracy', both ‘literacy’ and ‘numeracy’ appear to still hold a narrow meaning, where they primarily concern skills in being able to work with words and numbers.

Design and Technology subjects have been cited as being of possible benefit to performance in the ‘Space and Shape’ element of PISA (Close and Shiel 2009; Perkins and Shiel 2016; Shiel et al. 2006), however, these subjects are optional areas of study for students in Irish secondary schools. This has a subsequent effect on subjects in terms of provision and take-up. The STEM Education Policy Statement 2017-2026 (DES 2017) highlights this as a point of concern.

Discussion

The 21st century technological world demands that people need to be able to understand, use and reflect on different forms of information. This paper has highlighted that the concept of ‘literacy’ is complex, however as the analysis has highlighted, literacy as defined in the Irish context does not explicitly encompass the broad dimensions of Spatial Literacy as presented in the literature. Within Irish policy more traditional understandings of literacy, such as reading, writing and arithmetic dominate. This focus perhaps reflects international pressures as a result of international metrics of literacy as defined in PISA and TIMSS. Notwithstanding this narrow focus, there is a level of treatment of Spatial Literacy within the Mathematics subjects in Irish schools, however, an analysis of the students’ performance in PISA and TIMSS highlights, their performance in key areas involving spatial concepts would suggest that its treatment in Mathematics is not comprehensive and points to quite a selective adoption of dimensions of Spatial Literacy that overlap with Mathematical Literacy rather than a more universal embracement of it. This gap in the reality of its treatment versus the rhetoric of the various policies reviewed suggests that while at a policy level broader conceptions of literacy are acknowledged, this has not percolated into day to day practices at a classroom level and may also reflect the prioritisation of other dimensions of literacy.

Looking specifically to Spatial Literacy, the literature has highlighted that justifications underpinning its use are strongly framed within a modern-vocationalist ideology (Carr 1998; McCormack et al. 2015) with its use primarily justified in terms of preparation of key professions particularly within the STEM arena. Less prominence is devoted to a more universal justification for its implementation across the curriculum based on broader educational and social rationales despite recognition of an increasingly greater visual environment brought about through the development of a digital visual world.

Turning to the Irish context, in-depth treatment of Spatial Literacy, focusing on 3-D spatial concepts, remains confined to design and technology subjects that have traditionally had a strong vocational focus. Its treatment in Mathematics remains quite narrow, focusing primarily on 2-D Euclidian geometry.

In exploring the reasons for the current state of play there are a number of possible explanations. Firstly, the lack of more in-depth treatment of Spatial Literacy could be a result of a lack of understanding of its wider dimensions and what therefore the Mathematics syllabus needs to encompass. For example, in the context of Singapore, a country that has consistently scored highest in measures of Spatial Literacy in PISA and TIMSS, there is specific treatment of 3-D spatial skills in the secondary Mathematics syllabus (MoE 2012). It could be therefore that more 'traditional' views of what constitutes the study of Mathematics in Ireland confines it to 2-D problems. On the other hand, these 3-D aspects of visual Spatial Literacy could be seen as outside the discipline of Mathematics and therefore while recognised are excluded on these grounds. An alternative explanation could point towards the traditional origins of the study of 3-D problems in the Irish educational system where they have been historically been housed within lower-status design and technology subjects (Lynch and McGarr 2014) and hence carry a level of vocational stigma influencing its more universal adoption.

As recognition of Spatial Literacy develops to be seen as a universally important skill for all, as outlined in the literature, it raises questions as to how it should be incorporated into the curriculum. One solution could be in a broader treatment within the compulsory subject of Mathematics. Positioning it within Mathematics would align with how it is seen internationally as reflected in international metrics of Literacy. As it is a compulsory subject with high status on the curriculum this would also ensure that all students would have exposure to it. On the other hand, the extent to which its adoption by Mathematics teachers is fully embraced could pose challenges given that it has to compete with existing, more established topics on the syllabus and the nature of assessment that would be required to capture the extent to which it has been acquired.

A more cross-curricular approach could be an alternative solution. This solution would involve the implementation of Spatial Literacy in all subjects. This approach would ensure that its treatment would be more applied and specific examples would be more contextualised at a subject level. However, giving all teachers responsibility could result in no change at all, as the adage goes, 'if it's everyone's job to feed the dog, the dog starves'. In addition the level of change required to incorporate this across the curriculum would be extensive and the logistical and resource demands would be very significant.

The previous solutions offered, where Spatial Literacy is incorporated into existing subjects, whether optional or mandatory, overlooks more fundamental challenges posed by the incorporation of critical skills and competencies in schools. For example, the need for Mathematics to encompass a broader treatment of Spatial Literacy, which draws on areas more traditionally associated with Technology and Engineering education, reflects an erosion of traditional subject boundaries in the area of STEM and beyond. Therefore a more extensive treatment of Spatial Literacy in Mathematics raises more fundamental questions about the traditional demarcation of STEM subjects and the way in which knowledge is treated in a discrete way in the curriculum. As more universal skills and competencies, which transcend any one subject of study, continue to move centre-stage, how the ‘traditional’ subject-based model of education responds to this change will ultimately determine the extent to which these key skills and competencies are achieved.

In concluding this section it is worth returning to the very concept of Spatial Literacy. In discussing the rise of the use of the term ‘literacy’ in education, Buckingham (2015) notes that the term ‘literacy’ carries a degree of social status. Therefore when this term is used in connection with other terms, that have had a traditionally lower status, in this case ‘visual’ and ‘spatial’, which in the Irish context are associated with low-status vocational subjects, it can elevate its status and give it greater significance than previously afforded. In this context, is the focus on ‘Spatial Literacy’, a form of ‘social mobility’ of a skill once confined to vocational subjects or does it represent more fundamental changes that need to be recognised? In this paper we have argued the latter, however one must also recognise that Spatial Literacy is one of many new literacies that have emerged in recent years that are all elbowing for space and recognition on the curriculum.

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