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This paper describes a novel study that aims to explore students' mathematical preparedness for STEM education at tertiary level in the Irish context. The study addresses the issue of student retention in STEM degrees by investigating the perceptions of three stakeholders – teachers, students and lecturers – on the mathematical preparedness of students for studying science and engineering at tertiary level. The study also examines the existence and perception of interdisciplinary STEM education in preparing students for the transition to tertiary level STEM learning. In this paper, we describe the rational and design of this pilot study at an Irish university, including the development of questionnaire instruments for teachers, students and lecturers. Further advancement of the study is also discussed, as well as the intention to design targeted support for first year students of science degrees.

Keywords: Interdisciplinary approach, mathematics, science, student attrition, STEM education.

Introduction

Internationally, there has been increased emphasis on Science, Technology, Engineering and Mathematics (STEM) education and the exigent need to provide quality STEM education at primary, secondary and tertiary levels, in order to increase the number and quality of STEM graduates (DES, 2017; Friedman, 2005; Sanders, 2009). With augmented political and economic focus in the last 20 years, STEM education and integration has come to the forefront of national and global policies. While recommendations have been made for integrative STEM education (see e.g. Breiner et al., 2012; Kennedy & Odell, 2014; Sanders, 2009), there remains some hesitancy about how exactly STEM should be integrated in an educational context (Blackley & Howell, 2015). In Ireland, there is a particular concern that students entering higher education are under-prepared to engage effectively with learning in STEM courses (DES, 2011). Mathematics and science especially are central to many STEM courses at tertiary level, with first year undergraduates often lacking the skills and knowledge in these subjects to successfully engage with their STEM degree. This paper describes a pilot study of students' mathematical preparedness for learning science and engineering at tertiary level in the Irish context. The authors aim to investigate the students' mathematical preparedness from three perspectives: first year students enrolled in science and engineering degrees at an Irish university; science and engineering lecturers teaching first year modules at the university; and senior cycle post-primary (second-level) mathematics and science teachers; as well as the existence and perceptions of interdisciplinary STEM teaching and learning. In addition, the way in which these groups use social media to develop informal networks between second and tertiary level education will be analysed. As data collection through questionnaire surveys is in process, this paper describes the rationale and design of the study.

Study rationale

Concerns about student retention in higher education is an international phenomenon, because of the very high drop-out rate from first year, and because Higher Education Institutes (HEIs) are held more accountable for students' success (Coertjens et al., 2016). In New Zealand, Jia and Maloney (2015) found that students enrolled in STEM degrees had the highest course non-completion rates. This is consistent with Rask (2010) and Chen and Soldner's (2013) findings in the US that grades and student retention rates are systematically lower in the STEM subjects of Sciences, Computing, Mathematics and Engineering. Similarly Malm *et al.* (2012) report that at the School of Engineering at Lund University, Sweden, the percentage of matriculating students who successfully complete their MSc engineering degree is about 60%. Most of the students who drop out do so during the first year, with a 21% attrition rate found in one particular year. Student progression and retention is now a national priority in Irish Higher Education, and is a major focus of national policy in recent years (HEA 2016). There has been a steady increase in student enrolments in higher education in Ireland over recent decades, with an increase of 7% between 2011 and 2016 of full-time undergraduate new entrants (HEA 2016). A report from the Higher Education Authority in Ireland found that the overall rate of non-progression (from year one to year two) was 11% for level 8 degrees in universities in the year 2012/13 (HEA 2016). Notably, prior academic achievement has been found to be the strongest predictor of non-progression in higher education (HEA, 2018). Therefore, there is a strong rationale for investigating students' transition to university, particularly for students enrolled in STEM degrees.

While several factors may impact on student progression, for science and engineering students, their level of mathematical knowledge is crucially important (HEA 2016), but even students with good marks in school mathematics can struggle with the mathematical aspects of third-level science and engineering courses. It is important to have good mathematical knowledge, but even more so to know how to use that knowledge in other subjects. However, very often mathematics is not taught in an integrated/interdisciplinary fashion at second level. Science and mathematics can be very separate as school subjects even where they share overlapping content (Czerniak & Johnson, 2014). It has been found that school mathematics teachers are often unfamiliar with the science subjects, and vice versa for science teachers (Walshe, Johnston, & McClelland, 2017). It is possible also that second level teachers are not teaching mathematics with students' future third-level STEM degrees in mind. Thus, the authors aim to address the following research questions in their study:

1. What are teachers, lecturers and first year students' perspectives on the level of mathematical preparedness of students for science and engineering degrees?
2. What understanding do teachers, lecturers and students have of STEM education, and in particular, integrated approaches to teaching STEM subjects?
3. Does social media indicate that networks exist that connect various actors across second and third level, such that the students' process of mathematical preparedness might be enhanced?

These research questions will be addressed in the first exploratory phase of the research. The authors aim to design and implement a pilot intervention for students at risk of failing their first-year science modules in the second phase which will be informed by the findings of this study.

Interdisciplinary education in STEM

Both in Ireland and internationally, education initiatives have often focused on improving individual disciplines in STEM (discipline silos) rather than integrating the collective. These efforts aim to enhance students' learning in each of the STEM disciplines through a focus on inquiry, problem solving and constructivist learning, which are essential skills for the 21st century. However, researchers have argued that for students to be fully prepared for future STEM careers in the real world, there needs to be an emphasis on interdisciplinary thinking (Asghar et al., 2012; Breiner et al., 2012). In conceptualizing what STEM means, many people do not have an interdisciplinary understanding of STEM (Breiner et al., 2012). *"Everybody who knows what it means knows what it means, and everybody else doesn't"* (Angier, 2010). In their study of faculty members' conceptualization of STEM, Breiner et al. (2012) found diverging views from both STEM and non-STEM disciplines. Becker and Park (2011) conducted a meta-analysis of STEM integration studies and found that STEM teachers are often unaware of the benefits of integration and school administrators often do not support integrative approaches as a means to motivate students' learning in STEM. Teachers' self-efficacy plays a vital role in successful teaching (Stohlmann et al., 2012) and teachers' content and pedagogical knowledge can influence their teaching self-efficacy. Stohlmann et al. noted that teachers' comfort with teaching integrated STEM lessons was also affected by their commitment to future integrative STEM teaching. Laboy-Rush (2011) avers that the success of integrative STEM initiatives is very much dependent on teachers' attitudes to changes in their teaching practice, and these attitudes can be influenced by teaching efficacy (De Mesquita & Drake, 1994). Teachers' attitudes to adopting an integrative STEM teaching approach can affect their commitment to such initiatives as well as influence their students' interest and motivation in STEM (Al Salami et al., 2017). In analysing the conceptual changes of teachers towards interdisciplinary STEM teaching, Al Salami et al. found that a year-long professional development programme elicited little or no change which is consistent with previous studies on teacher change. Findings did indicate however, a significant positive association between teachers' attitudes towards interdisciplinary teaching and attitudes to teamwork, and also between attitudes towards interdisciplinary teaching and teaching satisfaction. It should be acknowledged that while there are benefits to integrating STEM subjects, there are also costs to teachers and schools in terms of time, resources and developing expertise (Gresnigt, Taconis, van Keulen, Gravemeijer, & Baartman, 2014).

There are many definitions of interdisciplinary teaching and learning or integration, and many approaches and models suggested for how it can be applied in teaching (Hurley, 2001, Pang & Good, 2000). Terms used in the literature to describe integration include: interdisciplinary; multidisciplinary; transdisciplinary; thematic; integrated; connected; nested; sequenced; shared; webbed; threaded; immersed; networked; blended; fused; correlated, coordinated, and unified curricula (Berlin & Lee, 2005; Czerniak & Johnson, 2014). A common definition of integration does not exist, and this ambiguity is inherent in the sheer number of terms used to describe it.

Moreover, these terms can mean different things to different researchers (Czerniak & Johnson, 2014; Kysilka, 1998). Berlin and Lee note in their analysis of the literature on science and mathematics integration from 1990 to 2001 that while many theoretical models have been proposed; there is a 'critical need for careful conceptualization and additional research on integrated science and mathematics teaching and learning' (2005, p. 22). As part of this study, the authors aim to clarify what teachers, lecturers and students currently understand by interdisciplinary STEM education, with a view to developing interventions that could address any gaps or shortcomings that are found to exist in their current conceptualisations and practice.

Study design

The methodology for this study is Educational Design Research, characterized by iterative design and formative evaluation of interventions in complex real-world settings. Working with all stakeholders, i.e. practitioners and end-users, to inform, design, pilot and refine the elements of an educational intervention is an essential part of this methodology (Plomp & Nieveen, 2013). This paper describes the first phase of our study which is chiefly designed as exploratory, inductive research. Exploratory research aims to apply "new words, concepts, explanations, theories and hypotheses to reality with the expectation of offering new ways of seeing and perceiving how this segment of reality works, how it is organized, and more specifically how and in what way different factors relate to each other causally." (Reiter, 2017, p. 139). This understanding of exploratory research frames our phase 1 study design in investigating students' mathematical preparedness for learning science and engineering in first year of university. Our study is underpinned by the constructivist position that people construct knowledge and its meaning from their experiences (Driscoll, 2000). The authors hypothesize that university students' learning of science and engineering is affected by their knowledge of mathematics and their experience of learning mathematics/science in post-primary education. The authors further hypothesize that students' exposure to integrative, interdisciplinary-based learning in mathematics and science at post-primary level affects their mathematical preparedness for studying science and engineering at university. These hypotheses led to the formation of our four research questions in the introduction section of this paper. To answer our research questions, three questionnaires were designed, aimed at first year university students in science/engineering degrees, science/engineering lecturers and post-primary teachers teaching science and mathematics at senior cycle (the final 2 years of post-primary education in Ireland). Both quantitative, fixed-response items and qualitative, open-ended questions are employed in all questionnaires. To aid in comparative analysis, questionnaires contain similar sections and items, adapted where necessary to suit the intended participant.

All three questionnaires aim to determine the target groups' understanding of STEM education and interdisciplinary teaching. Items were adapted from Bayer (2009) to suit the Irish context, and to suit the target audience (teachers, lecturers or students). Each questionnaire also had items specific to the target group. For example, the teacher questionnaire addressed participants' team-teaching and collaborative planning experience, as research has suggested a link between teachers' attitudes to interdisciplinary teaching and attitudes to teamwork (Al Salami *et al*., 2017). Relevant parts are adapted for mathematics or science teachers. They are also asked about their use of specific teaching practices which have been highlighted in the literature as optimal in science and

mathematics teaching, and which may also be useful for interdisciplinary teaching (Stohlmann *et al.,* 2012; Zemelman *et al*., 2005). Teachers' views on their role preparing students for third level education, and their familiarity with third-level STEM courses is also investigated. For the lecturer questionnaire, respondents are asked to rate their level of knowledge of Senior Cycle science and mathematics subject curricula, as well as the relevance of mathematics to the first year module(s) they teach. An important aspect of the lecturer questionnaire is to investigate their perceptions of the mathematical gaps that new university students may have in terms of learning science/engineering at third-level. It has long been reported that students experience difficulties with transitioning into third-level for a variety of reasons, including the very different style of learning and teaching compared to school (Harvey et al., 2006; Lovatt & Finlayson, 2013). The student questionnaire therefore investigates student perceptions of their preparedness for learning at university generally, for example in terms of time management issues, critical thinking and conducting independent research (National Forum, 2015), as well as their preparedness for (understanding of and attitudes towards) utilizing their school mathematics within third-level science/engineering modules.

The second phase of our study involves distribution of the questionnaires with a sample of first year science/engineering students, science/engineering lecturers and post-primary teachers teaching senior cycle mathematics/science (currently in process). The student and teacher questionnaires are being distributed in paper form and the lecturer questionnaire will be an online version (SurveyMonkey). Once the questionnaires have been returned, the data will be analysed. Fixed-response items will be analysed statistically using the Statistical Package for the Social Sciences (SPSS). Analysis will include descriptive statistics, reliability testing and correlation of items and variables. Comparative analysis will be performed within and between participant groups. Open-ended items will be analysed using inductive content analysis to derive themes relating to the research questions. A search of social media sites such as Facebook, Twitter and Instagram will be conducted to examine existing networks between second and tertiary level in relation to student preparedness for STEM degrees.

Findings will be used to design an intervention aimed at supporting students at risk of failing first year science modules. It is intended that a more in-depth study on the issue of students' mathematical preparedness for studying science and engineering degrees as well as the existence and perceptions of interdisciplinary STEM teaching and learning will be conducted in light of the findings of this pilot study. A limitation of the pilot study is that the teachers who participate in the survey are not sourced as the prior teachers of the first year students participating in the study. As such, in the subsequent study the authors will aim to survey teachers from the post-primary schools previously attended by the first year students to enhance insight into the issue of transition to science and engineering degrees. Further study will also involve the implementation and evaluation of the designed intervention for first year science degree students.

Conclusion

This paper has described an innovative pilot study in the Irish context. The study aims to address two issues of utmost importance to STEM education interests on a national and international level.

The first issue, relating to student transition to STEM degrees and student retention in STEM degrees, is a priority not only for educators, but also for policy makers and industry. The authors seek to gain new insight into the preparedness of first year students in science and engineering courses, with a particular focus on students' mathematical preparedness. This insight will be enhanced through the perceptions of three stakeholders in the student transition process; post-primary teachers, university lecturers and students in first year of university. Our findings in this study will also be used to develop targeted support for these students. The second issue we address is perceptions and understanding of interdisciplinary STEM education, which has received increasing attention from researchers internationally, but little research exists in the Irish context. Our study seeks to fill this gap and contribute to the international research. In particular, we take a novel approach in examining the role of interdisciplinary STEM learning in student preparedness for STEM education at tertiary level.

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