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ORIGINAL ARTICLE

Tackling the transition—the English mathematics register and students learning through the medium of Irish

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Abstract The explosion of Gaeilge (Irish)-medium primary and secondary schools has played a crucial role in the rebirth of our native language in Ireland. The popularity of attending Gaeilge-medium education is significant, and continues to increase annually (Gaeilscoileanna Teo 2008). However, the majority of Gaeilgeoirí (students who learn through the medium of Gaeilge) face an imminent transition to English-medium mathematics education, be it at second or third level education. This paper presents a theoretical model for investigating the transfer between different languages for learning mathematics and for interpreting the findings emerging from the Irish context. Key findings include that Gaeilgeoirí at secondary level experience a disadvantage when assessed through the medium of English; at both transitions Gaeilgeoirí experience difficulties with the syntax, semantics, and mathematics vocabulary of the English mathematics register; and at third level Gaeilgeoirí are unaware of the language difficulties that they are experiencing.

Keywords Mathematics register · Educational transitions · Language mediums for learning mathematics · Irish context

Introduction

A significant language shift has taken place in Ireland – Gaeilge (Irish) has become fashionable. It is difficult to locate where and when this change began but political and social issues have played a significant influence in this development. In

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particular, the explosion of Gaeilge-medium primary and secondary schools throughout the country has played a crucial role in the rebirth of our native language. Previously Gaeilge-medium education was limited to remote isolated parts of Ireland known as Gaeltachtaí (all-Irish speaking districts). However, the rise in popularity of attending Gaeilge-medium education is significant (Fig. 1). The authors' research is concerned with Gaeilgeoirí (students who learn through the medium of Gaeilge) *in the transition* from Gaeilge-medium mathematics education to English-medium mathematics education in Ireland. This transition can take place at the primary to secondary interface or at the secondary to third level interface, and both transitions were investigated in this research project. The purpose is to identify the key features of the English mathematics register that pose problems for Gaeilgeoirí experiencing this transition. It is anticipated that other English-as-an-additional-language (EAL) students would experience similar problems when encountering the English mathematics register for the first time. EAL students will be required to process English mathematical text when engaged in mathematical learning. Depending on the student's previous language for learning mathematics (e.g., French, Arabic, an Aboriginal language), differences will exist between the orthography, the syntax, the semantics, and the phonology of the previous language of learning and English, the new language of learning (Galligan 2001). Accordingly this may impact on how EAL students process English mathematical text. Within the Australasian context migration is frequent for educational and work purposes, and indigenous groups are present within countries such as Australia (Aborigines) and New Zealand (Māori). The theoretical model presented in this paper, in conjunction with the findings emerging from the Irish context, can provide a basis for investigation within other mathematical learning contexts in which EAL students are present. This research is the first of its kind to be undertaken in the Irish context and accordingly significant contributions have been made both nationally and internationally to this area of mathematics education (see Ní Ríordáin and O' Donoghue 2009).

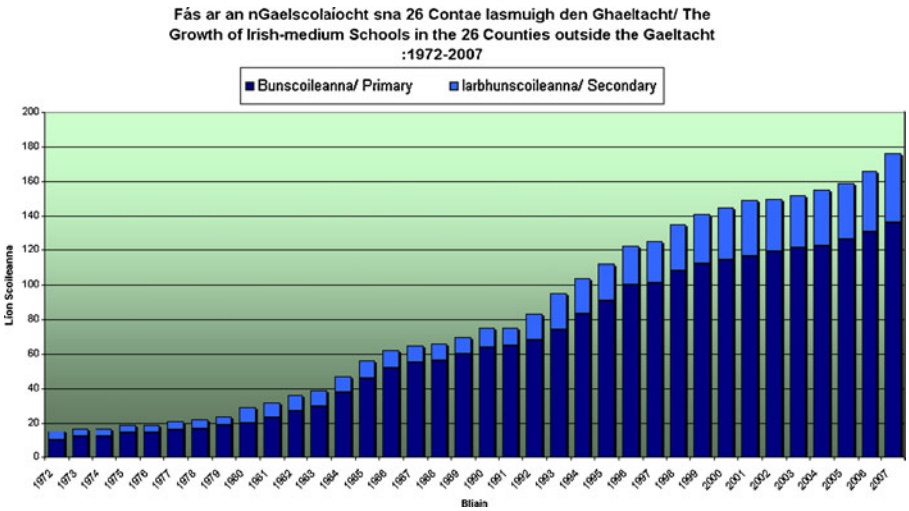

Fig. 1 Growth of Gaeilge-medium primary and secondary schools in the Republic of Ireland (outside of Gaeltacht regions)

Some relevant literature

There is growing recognition that language (and bilingualism/multilingualism) plays a key role in mathematics teaching and learning (Barwell 2009). Given the increase in international migration, the changing status of minority/indigenous groups, and the dominance of English as a language for learning and teaching mathematics, many students face a transition to learning mathematics through the medium of English (Barwell et al. 2007). Much diverse research has been undertaken on the effect of second language teaching in mathematics education (Adler 1998; Barwell 2009) but this research paper is specifically concerned with investigating the difficulties encountered with the English mathematics register when English is the students' second language of learning. Bohlmann (2001) highlights the importance of language for mathematical learning given that "It is the medium by which teachers introduce and convey concepts and procedures, through which texts are read and problems are solved" (p. 6). For EAL students, the challenge is twofold in that they have to acquire the new language of learning, as well as learn mathematics through the medium of a new language (Bohlmann 2001). Being proficient in conversational English does not guarantee successful learning in mathematics. As Barton and Neville-Barton (2003) emphasise, proficiency in "mathematical English" is an important factor in learning mathematics. Naudé's (2004) work supports this view. Her comparative study between Afrikaans students that attended English lectures and Afrikaans students that attended Afrikaans lectures found that there was no significant difference in performance between the two groups, even though the Afrikaans students attending the English lectures were academically stronger in general. The finding suggests that the Afrikaans students attending English lectures were experiencing a disadvantage due to not being proficient in mathematical English. Similarly, when examining the influence of language on the mathematical performance of children, Dawe and Mulligan (1997) concluded that teachers need to encourage students to recognise and distinguish between "mathematical" English and "natural" English as these are sources of confusion and lead to errors in performance.

A number of studies have compared bilingual students' performance on word problems with performance of monolingual students (e.g., Clarkson 1991, 1992; Clarkson and Galbraith 1992; Secada 1991) or when using different languages (e.g., Adetula 1989, 1990). These studies are difficult to undertake and Mestre (1986) highlights this. He compared groups of bilingual Hispanic students and monolingual students, all undertaking a degree in engineering at university. All students completed a reading test in English, an algebra test, and a mathematics word problem test. No significant difference was found between the monolingual and bilingual students' performance on the algebra test, but on the word problem test the bilingual students were slower and less accurate than the monolingual students. The results of these two tests imply that the difference may not be attributed to the bilingual students having a lesser ability in mathematics. Also, the vocabulary employed in the word problems was suitable for the bilingual students' level of English language proficiency. This implies that the reading and interpretative demands of the mathematics word problem test was a source of difficulty—"knowing the vocabulary in a word problem is no guarantee that the

mathematical relationships…will be appropriately interpreted [by non-native speakers]" (Mestre 1986, p. 399). This evokes the need to investigate further elements such the syntax and semantics of written mathematical text that may pose problems for EAL students.

Structural differences between the English and Mandarin languages are factors responsible for differences found in the performance of third-level Australian business studies students (Galligan 1995). Three tests were carried out, each in the students' first language, and they involved pure calculations, context-free word problems, and word problems in context. Students achieved similar results on the mechanical problems, but the word problems caused difficulties for non-English background students, thus highlighting their language difficulties. Galligan's (2001) review of differences between the English and Chinese language found large differences in the syntax, semantics, orthography, and phonetics between the two languages. For example, Chinese noun phrases tend to be left-embedded and this may affect cognitive processing. But with respect to English, the cognitive processing load is greater as the reader must remember the descriptive clause before dealing with the sentence. Accordingly, the easier syntax and better structured word order may facilitate access to the target question (Galligan 2001). There is little use of the passive voice in Chinese mathematical texts, whereas in English mathematical text passives are common. It is expected that passive voice requires more processing than active voice (Galligan 2001). The use of compound words in Chinese mathematical texts helps describe the concept, as opposed to labelling in English, for example the word for "diameter" in Chinese when translated to English means straight line. Naturally this lends to a better understanding of mathematical concepts (Galligan 2001). Subsequently some of the differences outlined in Galligan's review may have consequences for the processing of mathematical text.

Three important studies have taken place at second- and third-level education in New Zealand with the primary focus on the mathematics learning of students for whom English is a second language (Barton et al. 2005). These studies were stimulated by an interest in investigating the relationship between mathematics and language, and the need to support students in the transition to English-medium education. Findings from the first study indicate that students learning through the medium of a second language (English) have greater-than-anticipated difficulties with text, and that they wrongly rely more on symbolic modes of working (Barton and Neville-Barton 2003). The second study had important findings demonstrating that second-language mathematics learners were unaware of their disadvantage (Barton et al. 2004). The above studies culminated in the design and implementation of the third study (Neville-Barton and Barton 2005). The research questions were concerned with the relationship between English language proficiency and mathematics achievement, and the particular features of the mathematics language that cause difficulties for students for whom English is a second language. The findings concluded that students experience a disadvantage, estimated to result in a decrease in performance of 10 to 15%, in mathematics as a result of language difficulties. The study confirmed that students are not aware of the difficulties they are experiencing. Diverse language features were identified as sources of difficulties, with word order and prepositions the most significant causations, in addition to logical structures (e.g., implication, conditionals, and negation). As anticipated,

mathematical questions expressed in everyday contexts contributed to the difficulties experienced by the students.

Clarkson's (1991) work with Papua New Guinea (PNG) bilingual students confirmed that comprehension errors constitute a large number of the errors made by PNG students (grade 6) when solving mathematical word problems. He argues that competence in the mother tongue as well as in English plays an important role in the comprehension of mathematical text. Latu (2005) found that Pasifika students' learning of mathematics through the medium of English was hindered by an underdeveloped mathematical discourse in both Tongan and Samoan languages and accordingly underdeveloped ability to deal with complex mathematical sentences, phrases, and mathematical terms. This demonstrates the importance of a student's first language of learning for the transition to English-medium mathematics education.

Clarkson's (2007) more recent research concentrated on high-ability Australian-Vietnamese bilinguals and their use of language(s) when involved in mathematical problem solving. He found that the students rely on language switching and thus their competencies in *both* languages are of importance to how they perform on mathematics problems. When language switching (English to Vietnamese) did occur, it was mainly translating entire problems (as opposed to individual words). This may be as a result of all students having "a well-developed mathematical register in Vietnamese" (Clarkson 2007, p.209) and suggests that it is more than just vocabulary that plays a significant role in the transition to learning mathematics through the medium of English. This process of language switching appears to be an "unconscious and unplanned" action, but shows that there was a move towards using the primary language of instruction in the classroom (Clarkson 2007, p. 212). However, Clarkson (2007) places an emphasis on the role that mathematics teachers can play in enhancing their students' mathematical ability, given their knowledge of language switching use by bilingual students.

The process of learning mathematics involves the mastery of the mathematics register (Setati 2005). This allows students to communicate their mathematical findings in a suitable manner, and "without this fluency, students are restricted in the ways that they can develop or redefine their mathematical understandings" (Meaney 2005, p. 129). Developing a child's mathematical register provides them with analytical, descriptive, and problem-solving skills within a language and a structure so that they can explain a wide range of experiences. Once the register is mastered, learners will have the ability to listen, question, and discuss, together with an ability to read and record. While many students who learn mathematics in their mother tongue (e.g., Gaeilge) have difficulty in acquiring the mathematics register, this difficulty is heightened for those who must learn it in a second language (e.g., English). Learners have to cope with the new mathematics register, as well as the new language in which the mathematics is being taught (Barwell 2003; Setati and Adler 2000).

A key issue that causes significant problems for second-language learners (as well as monolingual learners) is the number of *borrowed/ambiguous* words (for example, "mean", "product", "common", "even") from everyday English (Durkin and Shire 1991; Pimm 1987). These words tend to be ambiguous due to having one meaning in the mathematics register, while another meaning in their everyday use (Yushau

and Bokhari 2005). Also, Rudner (1978) found that *conditionals* (if, when); *comparatives* (greater than, the most); *negatives* (not, without); *inferentials* (should, could, because, since); *low information pronouns* (it, something); and *lengthy passages* are sources of difficulty and hinder students' interpretation and understanding of mathematical word problems. The use of *specialist vocabulary* (for example, "quadrilateral", "parallelogram", and "hypotenuse") can lead to misunderstanding and misinterpretation of mathematical tasks. Students tend to encounter these terms only within the mathematics classroom and they are unlikely to be reinforced outside of it (Pimm 1987). *Context* is also a key issue. "Words can change their meaning depending on their context within the mathematics lesson" (Gibbs and Orton 1994, p. 98). In terms of language analysis, this is known as *semantics* and *syntax*—establishing the meaning in language (semantics), or the relationship and representation between signs and symbols, as influenced by the structure of the sentence (syntax). Due to the multiple meanings that various words can have, the context is vital in determining the correct interpretation. Finally, s*ymbolism* is one of the most distinctive features of mathematics. It is crucial for the construction and development of mathematics. Unfortunately "symbolism can accordingly cause considerable difficulties to those whose mother language has different structures" (Austin and Howson 1979, p. 176). One of the requirements for mathematical learning is that students can interpret the mathematical text and convert it to an appropriate symbolic representation, and perform mathematical operations with these symbols (Brodie 1989).

Registers exist in many disciplines (e.g., science, technology, etc.) but likewise everyday English can be classified as a register. Given the importance of mathematics for science, engineering, and technology subjects, the need for all students to develop fluency in the mathematics register is heightened. The mathematics and everyday registers can interfere, often in subtle ways, in a learning environment. Thus learners need to recognise each of these registers so as to identify which is being used at any given time (Sierpinska 1994), and this is a particular challenge many Gaeilgeoirí encounter when transferring to learning mathematics through the medium of English.

These *language features* were employed by the authors as a framework for investigating the sources of language difficulties Gaeilgeoirí encountered with the English mathematics register when completing mathematics word problem tests (see Tables 1 and 2).

Theoretical model

The previous review of literature demonstrates that learning mathematics through the medium of English may cause difficulties for students for whom English is not the first language of learning. The proposition that some languages have greater cognitive demands than others is difficult to demonstrate but other researchers have verified that processing English mathematical word problems requires a high cognitive demand (Lewis and Mayer 1987; MacGregor 1991). Important research into the influence of language on mathematical learning has been undertaken in the Australasian context, and key findings emerging can be utilised in other research

studies being undertaken in second-language mathematics learning contexts. Findings transpiring from the Irish context can reinforce previous findings while also providing new insights into the difficulties encountered with the English mathematics. This section of the paper will present a theoretical model for investigating language issues that can be employed in diverse language contexts (the Irish context in this case) and help interpret the findings emerging from a bilingual context, hence the significance of this study.

A number of influential theories were drawn upon to inform the design of the theoretical framework supporting the research undertaken. The following is a diagrammatical representation (Fig. 2) of this theoretical framework and the interconnection between the key concepts. Each will be discussed subsequently.

A large body of research demonstrates that when abilities in both languages are continued and developed throughout schooling, learners develop a deeper understanding of language and its functions (Cummins 2002). The assumption that languages are stored separately in the mind (separate underlying proficiency (SUP)) is false (Baker 2001). An increase in one language will not result in an imbalance and loss of a portion of the other language. A more pertinent description of language structure within the mind is Cummins's (1980) common underlying proficiency (CUP). The CUP model (Fig. 3) is depicted in the form of two icebergs, which are separate above the surface. Therefore, at first sight both languages are different, but underpinning the languages is a central processing unit where storage of both languages occurs and the languages are not independent of each other (Baker 2001; May et al. 2004). For example, students who learn mathematical operations (addition, subtraction, multiplication, division) in Gaeilge will also be able to perform the same operations in English. Accordingly interplay exists between both languages.

There are two individual registers that bilingual students have to develop and accomplish in their first (L1) and second (L2) languages. The basic interpersonal communicative skills (BICS) register relates to communication skills and conversa-

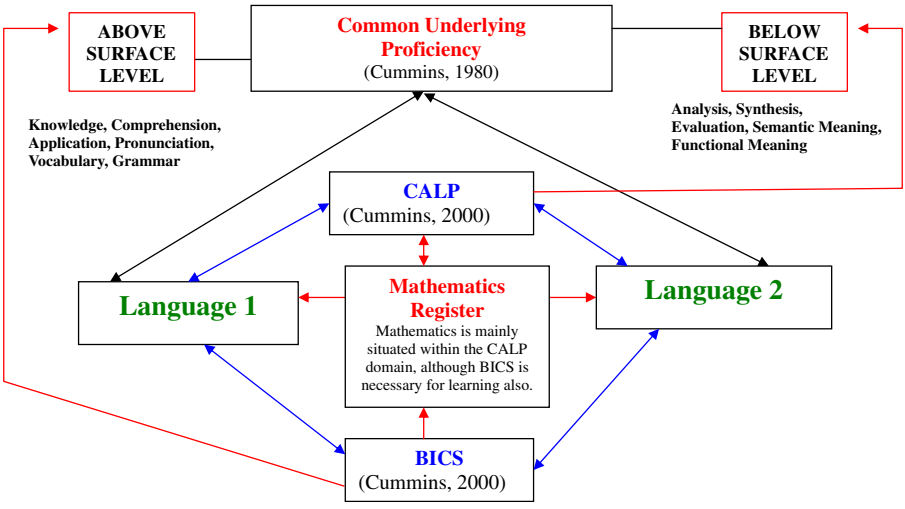

Fig. 2 Theoretical model for investigating the transition between languages for learning mathematics

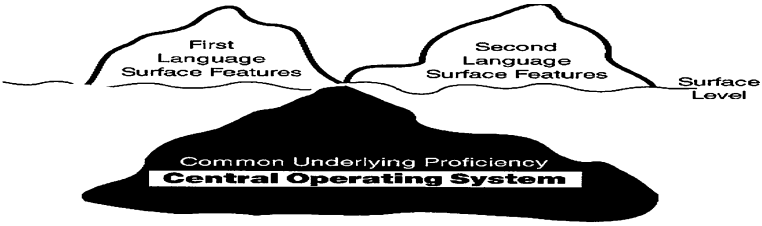

Fig. 3 Model of Common Underlying Proficiency (Baker 2001, p.165)

tional competence. It relies on phonological, syntactic, and lexical skills required to function in everyday contexts—the majority of the time these contexts are cognitively undemanding and contextually supported (May et al. 2004). Competence in BICS in a second language is achieved within 1–2 years (Cummins 2000). On the other hand, cognitive academic language proficiency (CALP) is required for context-reduced academic situations. CALP demands manipulation of the surface features of a language in impersonal contexts (May et al. 2004). The skills required are higher order in nature, such as analysis, synthesis, and evaluation. Cummins (2000) argues that these skills are a prerequisite as they provide students with the facility to use language as an instrument of thought in problem solving, and this justifies the assertion that learners need 5–7 years to acquire academic language proficiency in a second language.

CALP is a more advanced language proficiency and is necessary before efficient learning can take place in general. Mathematics teaching and learning largely takes place within this language domain. Mathematical language is regarded as a distinct "register" within a natural language, for example Gaeilge or English, which is described as "a set of meanings that is appropriate to a particular function of language, together with the words and structures which express these meanings" (Halliday 1975, p.65). The mathematics register is situated both within a language and, more specifically, within the CALP domain of a language. The mathematics register consists of the special vocabulary used in mathematics (Gibbs and Orton 1994) and it is the language specific to a particular situation type (Lemke 1989). But it is more than just vocabulary and technical terms. It also contains words, phrases, and methods of arguing within a given situation, conveyed through the use of natural language (Pimm 1987). The grammar and vocabulary of the specialist language are not a matter of style but rather methods for expressing very diverse things (Ellerton and Wallace 2004). Each language will have its own distinct mathematics register and ways in which mathematical meaning is expressed.

According to Cummins (1979), in order for bilingual students to master the academic language proficiency of their second language, their common underlying proficiency must be well developed. What is important to note here is that, while second-language learners may display oral proficiency (BICS) in their new language of learning, it may take longer to acquire the decontextualised language skills (CALP) necessary to function successfully in a second-language classroom. Mathematics is mainly situated within the domain of CALP, although BICS is necessary for mathematical learning also. In order for Gaeilgeoirí to function within an English-medium environment (L2), they require sufficient development of their CUP (Cummins 1979). The authors strongly feel that the distinction

between language registers facilitates an explanation of bilingual students' relative success/failure when encountering a new language of instruction in educational contexts. Gaeilgeoirí not only have to develop proficiency in the academic register in English but also learn new mathematical content in their second language for learning.

Methodology

The following sections provide a description of the study undertaken. The research was undertaken as part of the principal author's doctoral studies and a similar description of the methodology is provided in Ní Ríordáin and O' Donoghue (2009).

Test instruments

Mathematical word problems were utilised for identifying the specific sources of difficulties Gaeilgeoirí encounter with the English mathematics register when in the transition from Gaeilge-medium primary and secondary education. The word problems were specifically designed such that features of the English mathematics register (as identified by the literature) could be identified as sources of difficulty for Gaeilgeoirí at each transition (see Tables 1 and 2). Word problems have developed a reputation in mathematics education as being difficult for all learners (Verschaffel et al. 2000), but especially for students learning through the medium of a second language (Secada 1992) as such problems they "represent a language within a language" (Adetula 1990). Word problem are exceptional in encouraging students' mathematical thinking, as well being useful for identifying learners' language problems (Gorgorió and Planas 2001).

In subsequent sections of this paper we will discuss participants' performance on a variety of mathematical word problem tests. Due to ethical issues and time constraints, the authors were unable to conduct clinical interviews with the participants. The word problems were designed to assess specific language difficulties, and these are outlined in Tables 1 and 2. Different tests were completed at each of the transitions—primary to secondary, and secondary to third-level mathematics education. A description of the tests employed follows:

(a) *Mathematics Word Problem Test at the Primary to Secondary Transition*

The English mathematics word problem test consisted of 12 word problems, with a number of subparts in some of the questions. The word problems were constructed using standard mathematics textbooks for first-year secondary students in Ireland to ensure that the problems were realistic and reflective of the situation that Gaeilgeoirí encounter on transitioning to secondary education (Maxwell and Evans 2000; Morris 2000). Appropriate piloting took place in which students completed the test instruments and teachers provided feedback via a questionnaire on the word problems utilised, so as to minimise difficulty with wording, content, and

Table 1 Sources of difficulty in the mathematics word problems at the transition to secondary education[a]

Sources of difficulty	The word problem question(s) in which the source of difficulty occurs.
Borrowed words	Question 4; Question 9;
Comparatives	Question 5; Question 7; Question 11;
Conditionals	Question 7; Question 8;
Implications	Question 4;
Inferentials	Question 9; Question 11;
Lengthy passages	Question 3; Question 9;
Low information	Question 1; Question 2;
Negatives	Question 9;
Semantics	Question 3; Question 5; Question 6; Question 7; Question 8; Question 10; Question 12;
Symbolism	Question 3; Question 8; Question 9;
Syntax	Question 1; Question 3; Question 4; Question 5; Question 6; Question 8; Question 10; Question 11; Question 12;
Vocabulary	Question 2; Question 3; Question 4; Question 5; Question 6; Question 9; Question 10;

[a] The identification of the sources of difficulties (Tables 1 and 2) within the individual questions in the English mathematics word problem tests was based on those identified in the literature

Table 2 Sources of difficulty in the mathematics word problems at the transition to third-level education

Sources of difficulty	The word problem question(s) in which the source of difficulty occurs
Borrowed words	Question 4;
Comparatives	Question 6;
Conditionals	Question 7; Question 11; Question 12; Question 14; Question 15; Question 16;
Lengthy passages	Question 5; Question 7; Question 8; Question 13; Question 14; Question 15;
Low information	Question 2; Question 3; Question 8; Question 10; Question 12; Question 14; Question 17; Question 18; Question 19;
Semantics	Question 1; Question 2; Question 3; Question 5; Question 6; Question 7; Question 8; Question 11; Question 13; Question 14; Question 15; Question 16; Question 17; Question 18; Question 19
Symbolism	Question 2; Question 13; Question 16;
Syntax	Question 1; Question 3; Question 4; Question 5; Question 6; Question 7; Question 8; Question 9; Question 10; Question 11; Question 12; Question 13; Question 14; Question 15; Question 16; Question 17; Question 18; Question 19;
Vocabulary	Question 1; Question 2; Question 4; Question 5; Question 6; Question 9; Question 11; Question 13; Question 15; Question 16; Question 17; Question 18; Question 19;

format in the final versions (Allalouf et al 1999). All Gaeilgeoirí at this transition also completed a *parallel version* of the test instrument in Gaeilge so that the translation in each language was as accurate as possible while maintaining appropriate wording in each language (Evans 2007). Therefore, the Gaeilge version of the test contained the same number and type of questions as the English version. The purpose of this was to allow comparison of performance in the two languages, and identification of sources of difficulty in this transition. The order in which the tests were administered was changed for every second student in each group. This was to ensure the process checked the order effect (Adetula 1990), and there was no difference in test scores related to the order in which the tests were taken. The results on the English version of the test were used when comparison was undertaken with the results of the monolingual students. All the word problems had a readability level within the expected range for 12-year-olds (Flesch Reading Ease and Flesch-Kincaid Grade). This was the minimum age of participants in this study.

(b) *Mathematics Word Problem Test at the Secondary-to-Third-Level Transition*

The English mathematics word problem test consisted of 19 word problems, with a number of subparts in some of the questions. Sixteen of the word problems were constructed using the PISA framework (OECD 2006). This framework was chosen due to the emphasis it places on mathematical literacy. Also given that students at third-level education participate in different mathematics courses it is difficult to design a mathematics test suitable for all participants, and PISA provided a very appropriate framework for designing the mathematics word problems employed. The remaining three questions consisted of cloze-type questions (see Hater and Kane 1975). Several words were deleted at random from each of these questions and the participants were required to fill in the missing mathematical word in each of the blank spaces provided. Once again, appropriate piloting took place to minimise difficulty with wording, content, and format in the final version of the test (Allalouf et al 1999). All the word problems had a readability level within the expected range for 18-year-olds or younger (Flesch Reading Ease and Flesch-Kincaid Grade).

Also,

(c) *Questionnaire at the Secondary-to-Third-Level Transition*

Gaeilgeoirí in the transition from Gaeilge-medium secondary to English-medium third-level mathematics education also completed a questionnaire as part of the overall doctoral study. Findings from an aspect of this questionnaire (participants' rating of their ability in coping with the new language of learning) are included in this paper.

Subjects involved in the study

The secondary schools involved in this study were firstly identified by primary school principals (June, 2006) of Gaeilge-medium schools as enrolling Gaeilgeoirí in the transition from Gaeilge-medium primary to English-medium secondary

education. These secondary schools were contacted (September, 2006) and 5 agreed to partake in the research project (Oct.–Dec. 2006). Students from all-English-medium education were sourced at the same secondary schools and classes (students were streamed according to ability in class groups) as those into which the Gaeilgeoirí had transferred, in order to formulate a monolingual control group for comparison of performance on the mathematics word problems. Gaeilgeoirí who participated in the study at the primary-to-secondary transition were selected using the following criteria:

- They had studied mathematics entirely through the medium of Gaeilge at primary level,
- They were currently studying mathematics through the medium of English at secondary level, and
- All subjects were in their first year of secondary education.

In total 37 Gaeilgeoirí and 49 monolingual students participated in the study at this transition in education.

All Heads of Departments (HOD) of Mathematics in all universities, institutes of technology, and colleges of education were contacted in January 2007. There was a very low response rate and only 4 institutions agreed to participate in the study (Feb.–May, 2007). The HOD identified potential participants within their courses and the principal author made subsequent contact. Students from all-English-medium education were sourced in each of the class groups in which the participating Gaeilgeoirí were registered and were matched according to Leaving Certificate (final state examination at secondary education in Ireland) mathematics grade and overall points achieved, so as to formulate a monolingual control group for comparison of performance on the mathematics word problems. Gaeilgeoirí who participated in the study at the second-to-third-level transition were selected using the following criteria:

- They had studied mathematics entirely through the medium of Gaeilge at primary and at secondary education,
- They were now studying mathematics through the medium of English at third level, and
- They were in their first year of third-level education.

In total 15 Gaeilgeoirí and 6 monolingual students participated in the study at this transition in education.

It is important to note that differences may exist in terms of how mathematics was taught in the primary and secondary schools that participated in this study. All primary and secondary schools follow the same curricula in Ireland. However, we can not be assured that they all place the same emphasis on mathematics as a subject, and differing teaching and learning processes may be valued within individual schools. This may impact on students' performance on the tests administered. Gaeilge-medium schools in Ireland are expected to teach entirely through the medium of Gaeilge but the authors cannot guarantee that this was the case—if the teachers had not taught entirely through the medium of Gaeilge then this may have had an impact on the results emerging from the study.

Analysis

All the data collected was coded and imported into SPSS (version 13) for quantitative analysis. The relevant variables in each of the data sets were explored and tested for normality before application of the Mann-Whitney U test for significant relationships between the variables. Significance of the relationships explored was 0.05 or less for the results reported in this paper. Analysis of performance on mathematics word problem questions is described further in the findings section, along with identifying sources of difficulty encountered with the English mathematics register. Table 1 (primary to secondary) and Table 2 (second to third level) provide the details of the sources of difficulty within each individual mathematics word problem.

Findings

The findings from this study are presented in two subsections—findings from the primary-to-secondary transition, and the findings from the second-to-third-level transition.

Primary to secondary transition

Students in the transition from Gaeilge-medium primary level education to English-medium secondary education were administered the mathematics word problem test both in English and in Gaeilge. There were four questions for which there was no difference in performance between language mediums (Questions 1 (iii), 1 (iv), 4, and 9 (iv)) and one question (Question 8) in which Gaeilgeoirí performed better in English. However, there were nine questions in which Gaeilgeoirí performed at least 10% higher in Gaeilge than in English (Questions 3 (ii), 3 (iii), 5, 7 (i), 9 (iii), 10 (v), 12 (i), 12 (ii), and 12 (iii)). Overall, there was an average difference of 8.7% in performance between the English and Gaeilge mathematics word problem test, with Gaeilgeoirí performing better in the Gaeilge version. The finding has significant implications as it suggests that when Gaeilgeoirí are initially assessed through the medium of English, performance may not be reflective of their true mathematics ability. Naturally their performance may change over time given that these students are in their first year of secondary education. Also, given that Gaeilgeoirí at this transition stage on average performed better than their monolingual peers through the medium of English (see Ní Ríordáin and O' Donoghue 2009), the difference in performance between Gaeilgeoirí and monolingual students may be more considerable if language is taken into account. Thus, secondary mathematics teachers need to be aware of Gaeilgeoirí present in their English-medium classes and consider the implication language has on mathematics learning and assessment. Taking a closer look at the questions on which Gaeilgeoirí performed 10% better on through the medium of Gaeilge than English, the, syntax, semantics, and mathematics vocabulary are the primary sources of difficulty for Gaeilgeoirí when answering these questions (see Table 1).

Also lengthy passages and borrowed words contributed to some of the difficulty they experienced with the English version.

In particular for Question 3, parts (ii) and (iii), there was a large difference in performance between English and Gaeilge (24.3% vs. 70.3% and 40.5 vs. 81.1%). The syntax of the Gaeilge version lends itself to a clearer understanding of what a "Highest Common Factor" is. In Gaeilge it reads "It is called the Highest Common Factor the number that is highest, which is 4" compared to "The highest of these, called the Highest Common Factor, is 4". The difficulty experienced by Gaeilgeoirí in answering this question correctly in English is likely due to a misunderstanding of the definition of a Highest Common Factor. Question 5 was also answered significantly better by Gaeilgeoirí through the medium of Gaeilge (40.5% answered it correctly) than through English (21.6% answered it correctly). Mathematics vocabulary in English is the primary source of difficulty in this question. Gaeilgeoirí were confused by the words "multiple" and "multiply" and may have been unsure of the difference in meaning. In Gaeilge two dissimilar words are used—"iolraí" (multiple) and "meadú" (multiply), thus lessening the confusion when interpreting and answering the question. Therefore the syntax, semantics, and mathematics vocabulary through the medium of English is a primary source of difficulty for Gaeilgeoirí in the transition to English-medium secondary mathematics education. Given that this is the first study of its kind to be carried out in Ireland, it provides a new insight into the potential difficulties Gaeilgeoirí may experience in the transition to English-medium education.

The average performance of Gaeilgeoirí at the transition to secondary education was 65.04% with a standard deviation of 15.55, whereas for monolingual students it was 60.27% with a standard deviation of 16.64. Monolingual and Gaeilgeoirí's performance on the mathematics word problem test through the medium of English was compared. There were 12 parts in which a significant difference in performance between the monolingual and Gaeilgeoirí was evident (Table 3). The monolingual students performed significantly better on Questions 1 (ii), 1 (iii), 1 (iv), and 5 (Mann-Whitney U, $p<0.05$). Question 1 required students to change numbers into their written form and some Gaeilgeoirí experienced difficulty with this task. The source of confusion for Gaeilgeoirí in Question 5 was the mathematical vocabulary employed, as discussed previously. This proposition is further supported by the fact that they performed better on this question through the medium of Gaeilge. Gaeilgeoirí in turn performed considerably better than their monolingual peers on Questions 9 (i), 9 (iv), 10—all parts, and 12 (iii) (Mann-Whitney U, $p<0.05$). This is a particularly interesting finding as both Questions 9 and 10 involve set notation and the understanding of abstract concepts associated with elements within a given set. The finding suggests that there may be something in the Gaeilge language that enables Gaeilgeoirí to do some specific abstract thinking and warrants further investigation. Neither the Gaeilgeoirí nor monolingual group performed well on Question 12, but Gaeilgeoirí performed significantly better on the third part. This part required interpretation and analysis of the context and information supplied. Thus Gaeilgeoirí's analytical skills may be better developed than those of their monolingual peers.

Table 3 Percentage of correct/incorrect responses to each mathematics question at the transition to secondary education

Question no.	Gaeilgeoirí		Monolingual	
	% Correct responses	% Incorrect responses	% Correct responses	% Incorrect responses
1(i)	89.2	10.8	98.0	2.0
1(ii)	86.5	13.5	98.0	2.0
1(iii)	91.9	8.1	100.0	0.0
1(iv)	89.2	10.8	100.0	0.0
2(i)	97.3	2.7	100.0	0.0
2(ii)	94.6	5.4	100.0	0.0
2(iii)	97.3	2.7	100.0	0.0
2(iv)	94.6	5.4	98.0	2.0
3(i)	73.0	27.0	69.4	30.6
3(ii)	24.3	75.7	30.6	69.4
3(iii)	40.5	59.5	44.9	55.1
4	70.3	29.7	63.3	36.7
5	21.6	78.4	51.0	49.0
6	37.8	62.2	28.6	71.4
7(i)	27.0	73.0	28.6	71.4
7(ii)	35.1	64.9	34.7	65.3
8	83.8	16.2	79.6	20.4
9(i)	83.8	16.2	61.2	38.8
9(ii)	83.8	16.2	77.6	22.4
9(iii)	62.2	37.8	51.0	49.0
9(iv)	81.1	18.9	63.3	36.7
10(i)	75.7	24.3	46.9	53.1
10(ii)	78.4	21.6	49.0	51.0
10(iii)	54.1	45.9	26.5	73.5
10(iv)	73.0	27.0	49.0	51.0
10(v)	70.3	29.7	51.0	49.0
11	75.7	24.3	79.6	20.4
12(i)	16.2	83.8	10.2	89.8
12(ii)	16.2	83.8	12.2	87.8
12(iii)	29.7	70.3	8.2	91.8

Second-to-third-level transition

At the transition from secondary to third-level education only one mathematics word problem test (in English) was administered to all participants. The average performance of Gaeilgeoirí at the transition to third-level education was 53.73% with a standard deviation of 18.03, whereas for monolingual students it was 57.07% with a standard deviation of 13.87. However, unlike the findings at the transition

from primary to secondary education, no significant difference was found between Gaeilgeoirí and monolingual students' performance on each of the individual questions (Mann-Whitney U, $p<0.05$, Table 4). This may be due to the low number of participants at this transition stage (15 Gaeilgeoirí and 6 monolingual students).

Table 4 Percentage of correct/incorrect responses to each mathematics question at the transition to third-level education

Question No.	Gaeilgeoirí		Monolingual	
	% Correct responses (no. of students)	% Incorrect responses (no. of students)	% Correct responses (no. of students)	% Incorrect responses (no. of students)
1	80.0 (12)	20.0 (3)	100.0 (6)	0.0 (0)
2	73.3 (11)	26.7 (4)	66.7 (4)	33.3 (2)
3	93.3 (14)	6.7 (1)	100.0 (6)	0.0 (0)
4	33.3 (5)	66.7 (10)	50.0 (3)	50.0 (3)
5	66.7 (10)	33.3 (5)	83.3 (5)	16.7 (1)
6	20.0 (3)	80.0 (12)	50.0 (3)	50.0 (3)
7(i)	100.0 (15)	0.0 (0)	100.0 (6)	0.0 (0)
7(ii)	86.7 (13)	13.3 (2)	100.0 (6)	0.0 (0)
7(iii)	73.3 (11)	26.7 (4)	100.0 (6)	0.0 (0)
8	80.0 (12)	20.0 (3)	83.3 (5)	16.7 (1)
9	26.7 (4)	73.3 (11)	33.3 (2)	66.7 (4)
10	73.3 (11)	26.7 (4)	100.0 (6)	0.0 (0)
11(i)	66.7 (10)	33.3 (5)	50.0 (3)	50.0 (3)
11(ii)	46.7 (7)	53.3 (8)	83.3 (5)	16.7 (1)
12	46.7 (7)	53.3 (8)	66.7 (4)	33.3 (2)
13	13.3 (2)	86.7 (13)	0.0 (0)	100.0 (6)
14	53.3 (8)	46.7 (7)	33.3 (2)	66.7 (4)
15(i)	80.0 (12)	20.0 (3)	100.0 (6)	0.0 (0)
15(ii)	26.7 (4)	73.3 (11)	50.0 (3)	50.0 (3)
15(iii)	46.7 (7)	53.3 (8)	50.0 (3)	50.0 (3)
15(iv)	66.7 (10)	33.3 (5)	83.3 (5)	16.7 (1)
15(v)	53.3 (8)	46.7 (7)	66.7 (4)	33.3 (2)
16	66.7 (10)	33.3 (5)	33.3 (2)	66.7 (4)
17(i)	20.0 (3)	80.0 (12)	16.7 (1)	83.3 (5)
17(ii)	20.0 (3)	80.0 (12)	16.7 (1)	83.3 (5)
17(iii)	20.0 (3)	80.0 (12)	16.7 (1)	83.3 (5)
18(i)	33.3 (5)	66.7 (10)	50.0 (3)	50.0 (3)
18(ii)	20.0 (3)	80.0 (12)	16.7 (1)	83.3 (5)
18(iii)	13.3 (2)	86.7 (13)	16.7 (1)	83.3 (5)
19(i)	80.0 (12)	20.0 (3)	83.3 (5)	16.7 (1)
19(ii)	60.0 (9)	40.0 (6)	33.3 (2)	66.7 (4)
19(iii)	26.7 (4)	73.3 (11)	33.3 (2)	66.7 (4)
19(iv)	60.0 (9)	40.0 (6)	16.7 (1)	83.3 (5)

However this finding is consistent with the previous finding of no significant difference in mathematics performance between bilingual and monolingual students at this transition stage (see Ní Ríordáin and O' Donoghue 2009).

Figure 4 shows that Gaeilgeoirí (bilingual) performed poorly on 15 of the 33 questions—Questions 4, 6, 9, 11, 12, 13, 15, 17, 18, and 19 (iii)—with less than 50% of the students providing correct answers to these questions. Similarly, the monolingual students performed poorly on 12 of the 33 questions—Questions 9, 13, 14, 15, 16, 17, 18, and 19. Again less than 50% of the group got these questions correct. Therefore, Questions 4, 6, 11, and 12 were the main sources of difficulty for Gaeilgeoirí in this transition in comparison to the monolingual group's performance on them. Question 4 and 12 are concerned with probability and some of the Gaeilgeoirí were not familiar with the mathematics vocabulary employed in this question and thus experienced difficulty with this question. It may be worthwhile investigating further Gaeilgeoirí's understanding of probability as these were the only two probability questions on the test instrument and they performed poorly in both. The vocabulary and syntax of Question 6 proved difficult for Gaeilgeoirí. In particular, Gaeilgeoirí were unfamiliar with the mathematical words "numerator" and "denominator." Although these are fundamental words of mathematics, previous research has found that it was the basic terminology and operations that were sources of difficulty for Gaeilgeoirí in the transition to English-medium education (Ní Ríordáin and O'Donoghue 2007). Question 11 is concerned with graphing, and the semantics of this word problem and the interpretation of the data presented posed problems for Gaeilgeoirí. Overall, the common characteristics of difficulty of these four questions were syntax, semantics, and mathematics vocabulary (see Table 2).

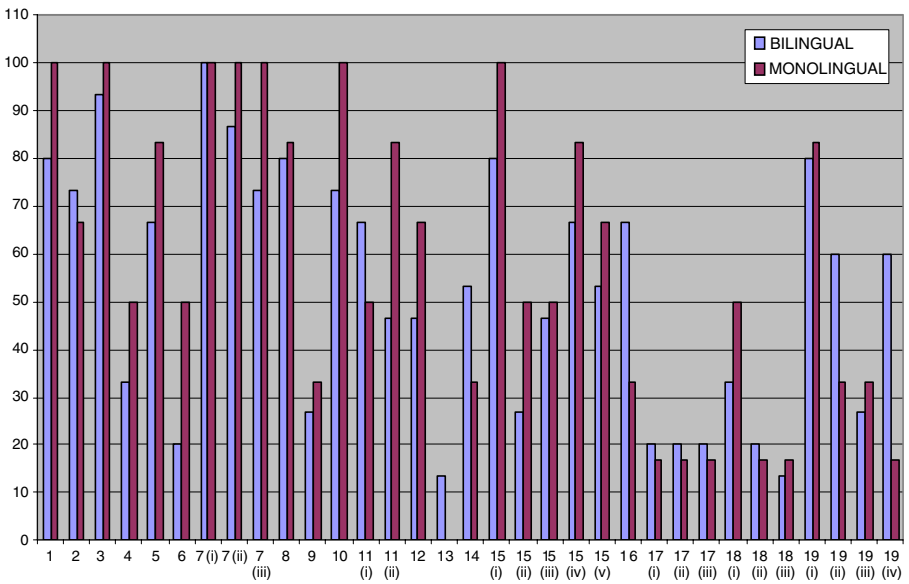

Fig. 4 Comparison of correct responses by Gaeilgeoirí (bilingual) and monolingual students at the transition to third level

Questions 9, 13, 15, 17, 18, and 19 were sources of difficulty for all students in the transition to third-level mathematics education. These questions contained complex syntax, semantics and mathematics vocabulary. What is interesting about Questions 17, 18, and 19 is that they are cloze-type questions in which the students were required to fill in the missing mathematical words in the blank spaces provided. Both groups performed poorly on these questions and this suggests that these students have a poor understanding and command of mathematics vocabulary and the mathematics register, which is worrying considering they are now in third-level education. Further investigation may be needed in relation to students' understanding, use, and command of the mathematics register at secondary education in Ireland.

The participants at third level were also asked to rate the difficulty of a series of questions related to mathematics and language (Neville-Barton and Barton 2005). The rating scale had four positions: 1 = not difficult; 2 = a little difficult; 3 = difficult and 4 = very difficult. The average rating for each is given in brackets after the particular question.

Understanding the English used by other students	**(1.07)**
Reading the blackboard/whiteboard/overheads	**(1.47)**
Understanding the English used by the lecturer/tutor	**(1.60)**
Reading mathematics textbooks	**(2.13)**
Reading photocopies/handouts given by the lecturer/tutor	**(1.67)**
Reading tutorial/exam questions	**(1.93)**
Understanding the mathematics content of lectures/tutorials/exams	**(1.93)**

All the average ratings were in the "not difficult" to "a little difficult" categories. Gaeilgeoirí are relatively confident in coping with English as their new medium for learning mathematics. However, this confidence is not reflected in their performance on the mathematics word problem test (median=53.73% with a standard deviation of 18.03). This suggests that Gaeilgeoirí are not aware of the influence of language on mathematics learning and that this lack of awareness is hindering them when transferring to English-medium education. This is reflected in the slight disadvantage they experience in mathematics performance in comparison to their monolingual peers (median=57.07% with a standard deviation of 13.87).

Discussion

The research reported in this paper provides information on the particular aspects of the English mathematics register that are sources of difficulty for Gaeilgeoirí in the transition from Gaeilge-medium to English-medium mathematics education in Ireland. Both the primary-to-secondary, and secondary-to-third-level transitions were investigated in this study. Some interesting findings are emerging and are consistent with results of similar studies carried out in Australia, New Zealand, and Papua New Guinea and will be discussed further in this section.

This research confirms that Gaeilgeoirí on average experience a disadvantage (8.7%) when assessed through the medium of English at the primary-to-secondary transition. Similar findings were found in the New Zealand context where EAL students at second- and third-level education experienced a disadvantage of between 10% and 15% due to language differences (Neville-Barton and Barton 2005). Accordingly, mathematical assessment undertaken through the medium of English at this transition may not be reflective of Gaeilgeoirís' true mathematical ability. Therefore mathematics teachers in English-medium secondary schools need to be aware of Gaeilgeoirí in their classes and cater for their language and mathematical needs.

This study of Gaeilgeoirí in the transition between language-learning mediums confirms for the first time that specific features of the English mathematics register pose problems for Gaeilgeoirí. This study is distinctive in that it investigated two key transition stages in education in Ireland—primary to secondary, and second to third level education. Syntax, semantics, and mathematics vocabulary in particular are sources of difficulty for Gaeilgeoirí at both transitions. The results support the necessity of proficiency in cognitive academic language proficiency (CALP) in English so that Gaeilgeoirí can cope with the new medium of learning (Cummins 2000). Gaeilgeoirí need to develop their ability in "mathematical English" to facilitate the transition to English-medium mathematics education at second- and third-level education (Dawe and Mulligan 1997; Frigo 1999; Galligan 1995). With awareness of the linguistic difficulties that Gaeilgeoirí encounter, mathematics teachers/educators can develop appropriate teaching aids and methodologies in order to cater for these specific learning challenges encountered by Gaeilgeoirí.

An interesting finding from the investigation at the primary-to-secondary transition is that Gaeilgeoirí performed better than the monolingual students on questions involving set notation and abstract concepts associated with elements within these sets. This suggests that there may be something that enables Gaeilgeoirí to do some specific abstract thinking. Further investigation into the mathematics register in Gaeilge may reveal a deeper insight into this proposition and how bilingualism may be having a positive effect on their mathematical learning (Clarkson 1992; Clarkson 2007; Ní Ríordáin and O' Donoghue 2009).

At third level it is basic mathematics vocabulary such as "numerator" and "denominator" that is the primary source of difficulty and this is due to the fact that Gaeilgeoirí acquired them through the medium of Gaeilge at a young age, used them entirely throughout their primary and secondary education, and would not have encountered the English version of the words until transitioning to third-level mathematics education. Gaeilgeoirí at third level are unaware of the language difficulties they are experiencing, a finding similar to that of Neville-Barton and Barton (2005). A possible explanation for this may be that they have competence in their everyday English language use but are unaware of the need for competence in specific academic English language, as employed in a typical lecture/tutorial situation at third level. This possibility suggests that Gaeilgeoirí may lack an awareness of a mathematical register and that learning has not taken place in either language to the point where the learner understands that there is a special register and consequently that there is something "missing." Also, instrumental mathematical

learning may be enough for these Gaeilgeoirí to pass their mathematical examinations at first-year undergraduate education and accordingly they may never realise that the nature of mathematical discourse alters at higher levels and further mathematical study (Barton et al. 2005).

A surprising result emerging from this research was that both the bilingual and monolingual students performed poorly on the cloze-type questions incorporated in the test instrument at third level. This implies that all students involved in this study at third-level education have a poor understanding of mathematics vocabulary and command of the mathematics register in English. It is expected that the students' CALP is underdeveloped in relation to English, and accordingly their ability to use the English mathematics register. Such a finding reflects the pedagogical practices employed in Irish mathematics classrooms in that students are required to use procedures of the discipline without acquiring and embracing the culture of the discipline (Lyons et al. 2003). Thus students are exposed to the procedural tools but lack authentic engagement in mathematical discourse and use of the mathematics register.

The significance of the findings outlined above lies in the potential role they can play in developing teaching resources and assessments to cater for Gaeilgeoirí in the transition to English-medium mathematics education. The findings provide us with the first insight into the potential difficulties Gaeilgeoirí may experience with the English mathematics register and accordingly Gaeilgeoirí can now be catered for in the transition between language mediums for learning. The findings emerging from the Irish context are consistent with those found in other bilingual contexts such as in New Zealand (Neville-Barton and Barton 2005), Australia (Dawe and Mulligan 1997; Frigo 1999; Galligan 1995), Papua New Guinea (Clements and Lean 1980; Lean et al. 1990), and Malawi (Kazima 2007). Studies in these contexts found that students learning through the medium of English (their second language of learning) experienced problems with syntax, semantics, and mathematics vocabulary in the English mathematics register, with language playing a key role in their mathematical performance (e.g. Clements and Lean 1980; Frigo 1999; Neville-Barton and Barton 2005), and that mathematics vocabulary in relation to probability is a problem only through the medium of English for Malawi students (Kazima 2007). Thus the authors' findings validate those found in other bilingual contexts in relation to difficulties encountered with the English mathematics register. This consensus contributes to the robustness of international findings and provides a starting point for assessing bilinguals on entering English-medium mathematics education, as well as providing a basis for developing teaching and learning resources and support measures for learning mathematics through the medium of English.

The authors strongly believe that emphasis should be placed on the common underlying proficiency as proposed by Baker (2001) and presented in the theoretical model. Outwardly both languages (Gaeilge and English) are different in conversation but internally both languages are merged and do not function independently of one another. Thus both languages contribute to, access, and use a central processing unit for mathematics learning and understanding. Gaeilgeoirí are faced with the challenge of recognising and developing awareness that both

languages are of importance to their mathematics learning and can be used to their advantage for developing mathematical understanding. Therefore, the challenge faced by Gaeilgeoirí is not in the relearning of mathematical concepts through the medium of English. Rather the challenge lies in transferring the mathematical skills and knowledge acquired through Gaeilge to the new language of instruction. Clearly, mathematics educators play a key role in this transfer of skills and this needs to be fostered within the Irish context.

Conclusion

Given that language plays a significant role in the learning and understanding of mathematics, Gaeilgeoirí face a considerable challenge when transferring to learning mathematics through the medium of English. Gaeilgeoirí are confronted with the language of mathematics when reading textbooks and worksheets, while also having to interpret and understand the English mathematical language used by the teacher. Knowledge of the difficulties that Gaeilgeoirí may experience with the English mathematics register in the hands of a discerning teacher can prove fruitful for easing the transition to English-medium mathematics education for Gaeilgeoirí. Although the findings emerging from this research are specific to the Irish context, they are important because of their applicability to other bilingual contexts. The theoretical model presented can be employed in order to investigate other EAL learning contexts. Given the increasing number of students learning in a dominant language that is not their first language, these findings are important to mathematics education (Adler 2001).

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