Ensuring methodological rigor for investigating the discourse development of bilingual mathematics learners

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Given the nature of investigating bilingual mathematics learners and learning environments, a key concern is how we can ensure that the rigor of our research is matched by the rigor of methodological frameworks and approaches employed. Our goal is to develop a theoretical framework and associated methodology and methods, in practice, in order to ascertain their suitability for investigating bilingual mathematics learners in an educational context. Moschkovich (2016) identified four key recommendations for conducting research on language: utilising interdisciplinary approaches, defining central constructs, building on existing methodologies, and recognizing central distinctions. Utilising Moschkovich's framework, this paper provides an appraisal of the methodology and methods to be employed in a research project examining bilingual mathematics learners.

Keywords: Methodology, methods, bilingualism, discourse, framework.

Introduction

Investigating mathematics and languages is a complex process. Therefore, the authors argue that there is a need to develop appropriate research methods in order to investigate language use and its impact on mathematics learning. In particular, we believe that the role of language(s) should be examined within mathematical activity and in situ (Barwell, 2016). This paper draws from the researchers' current study, which explores the potential for developing a coherent and integrated interpretive theoretical framework to examine whether differences in languages, and their use, by bilingual mathematical learners have a differential impact upon cognitive mathematical processing, while recognizing the social aspects of learning. The project, entitled 'M²EID: Mathematical Meta-level developments in English and Irish language Discourses', is a mixed-methods study, comprising video-recorded observations, questionnaires and cognitive interviews. The research project is being undertaken with first year, undergraduate students, who choose to study Mathematics through a bilingual approach (English and Irish) during their first year of undergraduate education at the National University of Ireland, Galway (NUI Galway). This option runs parallel to its English-medium counterpart, which typically receives a large intake (at least 150) of students. Four weekly lectures are provided in the Irish language with all terminology given bilingually. In addition, lecturers may opt to describe more complex concepts (such as limit of a function) bilingually. The lectures are supplemented by the provision of a weekly workshop in English in addition to an Irish-medium workshop.

Given the nature of investigating bilingual mathematics learners and learning environments, a key concern of this paper is to describe and discuss how we can ensure that the rigor of our research is matched by the rigor of methodological frameworks and approaches employed. It is imperative to review epistemology and associated underlying assumptions in order to make meaningful the methodology and methods of the research being undertaken in a bilingual mathematics education context. Grix's (2004) definitions of 'method' and 'methodology' are valuable for interpreting these constructs. A 'method' refers to the procedures or processes by which data is gathered; whereas, a 'methodology' refers to both the theory applied to inform the research and the data analysis strategies employed as appropriate to the data collected (via the specific methods). While Grix's definitions regulate our M^2EID research study, this paper focuses on possible methodological constructs that can frame such practice-based and context-driven bilingual classroom research. Consequently, the purpose of our paper is to describe and discuss the M^2EID research methodology and methods utilising Moschkovich's (2016, p.1) recommended constructs for conducting research on language use and learning in mathematics. These are: (1) using interdisciplinary approaches, (2) defining central constructs, (3) building on existing methodologies, and (4) recognising central distinctions while avoiding dichotomies. The paper is structured in accordance with these four recommendations and outlines their application to the main research study (M^2EID).

Using Interdisciplinary Approaches

Research on language and mathematics needs to consider interdisciplinary approaches in the development of methodology and methods and should be grounded in classroom discourse as well as language and bilingualism (Moschkovich, 2016). Therefore, this necessitates the development of integrative frameworks for examining, in situ, both the cognitive and social constructs of mathematics learning through and with languages.

In terms of the mathematics as a composite register comprising content, languages (e.g. English and Irish) and shifts between everyday and subject-specific registers, the authors emphasise the social and interpersonal aspects of language use and bilingualism in mathematics. Such aspects include the use of modes and gestures for communicating understanding and in particular, engagement in the situated and sociocultural practices of mathematical Discourses (Gee, 1996; Moschovich, 2002). Further, the M^2EID study is aligned with the perspective that learning mathematics is essentially a discursive activity in which learners form and actively participate in a community of practice (Lave and Wenger, 1991; Lemke, 1990). Therefore, learners develop unique sets of mathematical practices and modes of communicating with each other using all of the social, cultural and cognitive resources available to them. Consequently, a democratic process of learning emerges through a continuous cycle of negotiations in relation to views, beliefs, knowledge and meaning making (Moschkovich, 2002). So, by adopting this comprehensive sociocultural perspective of learning and language use in mathematics, this study requires an interdisciplinary approach to research within this educational field. Based on the sociocultural nature of mathematical concepts and how we understand and communicate this nature, it is vital to consider how various disciplines contribute to mathematics education. In order to address the aims of this study we will draw on the principles of Discursive Psychology, Cognitive Psychology, Semiotics, Pedagogy and Anthropology to progress a unified approach to researching learning and language use within mathematics. Due to the multi-ontological nature of this grounding framework for the M^2EID research project, it is essential to develop a dynamic and multifaceted methodological approach to the research, data collection and analysis strategies, which this paper focuses upon. Drawing on the body of relevant literature in this regard, the authors designed a methodology for investigating bilingual mathematics learners that is underpinned by Sfard's (2008) commognitive framework for examining learning. This framework, described later in this paper, is founded on the premise that thinking is a form of (interpersonal) communication, and that learning mathematics entails extending one's discourse.

Defining Central Constructs

Moschkovich (2016) emphasises that research studies need to be clear and explicit in relation to the key constructs utilised. Considering the centrality of discourse to the commognitive approach, it is important therefore, that our perspective of discourse is outlined first. Discourses encompass more than verbal and written language and the use of technical language; discourses also involve communities, points of view, beliefs, values, and pieces of work (Gee, 1996). Accordingly, we perceive mathematics as a discourse and a complex form of communication (Sfard, 2012). Gee's concept of Discourse will inform the examination of conceptual mathematical development of bilingual learners, linking both the cognitive and social aspects of language use.

Equally difficult and demanding is the task of defining bilingualism and in particular defining whether a person is bilingual or not. To illustrate these concepts further we employ Grosjean's (1999) model of a continuum of modes with monolingual and bilingual occupying opposite endpoints; this continuum reinforces an understanding of bilinguals using their languages independently and jointly depending on the context/purpose in which the language(s) is being employed. Appropriately then, we support a non-deficit view of bilingual learners, combining everyday and mathematical registers and view language(s) as a resource and a support for learning. Our research is particularly concerned with the role of bilingual students' languages in mathematics teaching and learning. We consider mathematical language as a distinct 'register' within a natural language and each language will have its own distinct mathematics register, encompassing ways in which mathematical meaning is expressed in that language. Specifically, we are concerned with conceptual mathematical activity. This encompasses a knowledge of what it means to understand a concept and an appreciation of how such an understanding can be constructed by a student, thus providing a model of cognition for the concept (Asiala, Brown, DeVries, Dubinsky, Mathews & Thomas, 1996). Given that language influences thought and thinking and that each language will have its unique manner of constructing the concept, it is critical to develop an insight into the role and effect of bilingualism/languages on conceptual mathematical learning. In addition, language(s) facilitate the development of a student's mathematics register and participation in discourse. Consequently, it is an essential instrument of thought and it is vital for understanding and combining experiences and for organising concepts (Vygotsky, 1962). We propose that there are differences 'between linguistically distinct versions of "the same discourse"' (Kim, Ferrini-Mundy & Sfard, 2012, p.2) which correspondingly impact on mathematical learning. Therefore, it is the use of language as an instrument of thinking that is of importance, as well as its effect on cognitive processing.

When examining bilingual mathematics learners, it is important to address the social use of language within the learning context, not just its role in cognition. As previously noted, Moschkovich (2012) emphasises the importance of learning being illustrated within the sociocultural practices of a certain setting. These practices involve a process of describing learners and communities and considering culture as a set of practices, which actively involve participants (Gutiérrez & Rogoff, 2003). Hence, bilingualism is described in terms of learners' participation in and use of language(s) for different purposes and particularly in the context of mathematical discourse. Similarly, Moschkovich (2012) emphasises the importance of discerning between the *conditions of* learning and the *processes for* learning, and the importance of describing the curriculum, courses/programmes and teaching and learning approaches utilised that yield successful outcomes for different groups of learners.

Due to the multifaceted process of investigating bilingual learners' use of language in mathematics education, it is vital that an extensive research methodology is developed to facilitate examination of central constructs such as discourse, bilingualism, and language use.

Building on Existing Methodologies

Consequently, research examining the development of mathematical learning and its relation to language draws on multiple theoretical frameworks to support investigations and accordingly methodological approaches (Moschkovich, 2016). Adopting Sfard's (2012) commognitive approach, data collection and analysis must adhere to its five methodological principles. These principles have been expounded upon to reflect our investigative framework and are 1) Operationality, 2) Completeness, 3) Contextuality, 4) Alternating Perspectives and 5) Directness. First, Operationality refers to the provision of a balanced account of the process through the sharing of practical, unambiguous stories that emerge from the study. Second, Completeness of the research emphasizes that the unit of analysis must comprise the entire discourse related to the topic. The researchers extended this principle for M²EID to include the documentation of such discourses (plausible developmental trajectories) in both the English and Irish languages. Third is Contextuality, which encompasses the premise that all interaction can be characterized as a learning event. We extend this, in the given context, to the need to examine when and how bilingual students/researchers use their language(s) in interactions. The fourth principle is that of Alternating Perspectives and explains the interchangeability of the researcher's insider/outsider methods of using words. This is intensified within a bilingual context because consideration must be given to both languages, their use within the given context as well as the possibility of significant differences between researcher and participant discourses. Fifth, the principle of Directness affirms that all descriptions of the study should commence with the specific raw data from the participants rather than the researcher's interpretation of that data. The application of these distinctive methodological standards will provide unique insights into the processes of bilingual mathematics learning and potentially contribute to the development of an empirical research base to ensure rigor in examining whether differences in languages, and their use, by bilingual mathematical learners have a differential impact upon cognitive mathematical processing.

Further to adopting Sfard's approach, it is vital to consider that epistemological assumptions inform methodology, which subsequently engender the methods employed to collect data. Therefore, aligned with the interdisciplinary foundations of the M²EID research project, the following are the proposed methods to be utilised in the study in order to ensure that a robust methodological framework and approaches support our inquiry.

1. *Discourse models:* This study will map the plausible developmental trajectories in both the English and Irish languages with respect to students' learning in various mathematical topics–e.g. functions–as consistent with the NUI Galway undergraduate module. The purpose of discourse models is to examine how language nuances and use affect learning (Kim et al., 2012).
2. *Videographic evidence*: This study will identify and explore when and how bilingual learners at NUI Galway employ each language (English and Irish) when engaged in mathematical learning. Specifically, the research will examine the cognitive functions of code switching and language use within a natural educational context, while also providing for the social aspects of learning. Videography is an effective method of examining teaching and learning experiences in naturalistic contexts and the affordances of modern technologies provide opportunity to document, share and analyse cases of particular practice (Derry, Pea, Barron, Engle, Erickson, Goldman, Sherin, 2010). All lectures and tutorials relating to the bilingual mathematics module in NUI Galway will be recorded and analysed as appropriate.
3. *Questionnaire*: The purpose of the first part of the questionnaire is to gather participants' background data. The second part of the questionnaire will engage participants in discourses related to particular mathematical topics (linked to the developed discourse models) with the option of utilising English or Irish or both languages. The Cognitive Aspects of Survey Methodology (CASM) model will guide participants in an activity series involving thinking-aloud their thought processes as they recall prior knowledge and experiences of mathematical discourses while answering the questions (Desimone & Carlson Le Floch, 2004). The focus will rest on conceptual mathematical activity based upon a variety of constructs, both familiar (such as functions and their analysis) and new (such as logical form, equivalence relations and classes, and related number theoretic constructs). A primary mathematical objective of the first year module in NUI Galway is to facilitate and develop advanced mathematical thinking.
4. *Video-recorded Cognitive Interviews:* Cognitive interview methods will be employed to explore respondents' explanations of the answers in order to acquire comprehensive knowledge about how well respondents comprehend, appreciate or even misinterpret the specific mathematics concepts central to the study (Desimone & Carlson Le Floch, 2004). Participants will engage in paired discussion of mathematical tasks (the same as in the questionnaire) and justify their answers where appropriate.

It is proposed that the combination of the above methods facilitates a progressive and incorporative investigation into the cognitive aspects of bilingual mathematics learning and to evaluate the impact of language*s* on mathematics learning in practice.

Recognizing Central Distinctions while avoiding Dichotomies

With Sfard's (2008) commognitive framework undergirding the approach, the following are key aspects of the proposed methodological framework under investigation (Ní Ríordáin & McCluskey, 2015):

- **Discourse changes**: If assuming the premise that mathematical learning involves initiation into the discourses of mathematics, then learning mathematics involves substantive discursive changes for learner. Sfard (2012, p.3) distinguishes between two types of mathematical learning (change in discourse) as follows: *object-level learning* (expansion of what is known already and is mainly accumulative) and *meta-level learning* (change of meta-discursive rules and is a more radical and complex change). Within the proposed framework, development refers to a change in discourses. Accordingly, we refer to the development of students' mathematical discourses as opposed to the development of the students themselves.
- **Sociocultural perspectives**: Discourse is more than just language. We utilize Gee's (1996, p.131) work which refers to Discourse as incorporating both talk and non-talk modes of participation such as gestures and artifacts, as well as participation in a social group. The employment of this definition synchronises with the concepts of discourses inherent within the sociocultural and Community of Practice perspectives.
- **Community of Practice**: Within the framework, thinking can be defined as the activity of communicating with oneself. Accordingly, mathematical thinking can be viewed as a discourse, which in turn is a form of communication and involves being part of a mathematical community. Taking this view, the language or languages in which mathematics is being learned becomes an important issue for consideration.
- **Conceptual learning**: Given that language influences thought and thinking (Vygotsky, 1962) and that each language will have its own way of constructing the concept, insight into the role and effect of bilingualism/languages on conceptual mathematical learning is critical. As previously mentioned, we do not view languages and registers as deficiencies but rather consider them as vital resources and skills for learning and language use in mathematics. Grosjean's (1999) concept of a continuum of modes will be employed to trace bilinguals' use of languages in situ.
- **Linguistic relativity hypothesis**: It is the use of language as an instrument of thinking that is of importance, as well as its effect on cognitive processing. The linguistic relativity hypothesis proposes that the vocabulary and phraseology of a particular language influences the perceptions and thinking of speakers of that language (Whorf, 1956). Accordingly, each language (e.g. English or Irish) will have a different cognitive system that will influence concept formation and development. The study adopts the premise that a language

influences, rather than determines, our mathematical thinking, and is cognisant of the impact of linguistic distinctions in a particular discourse on mathematics learning (Kim et al., 2012).

- **Meta-discourses**: The proposed framework is primarily concerned with meta-level developments in mathematical discourses. Since our focus is on bilingual mathematics learners, it is important that an analysis of the language(s) in which the discourse is taking place is conducted. In particular, the successive meta-discourses relating to mathematical topics of interest will be documented and compared between languages.
- **In situ research**: Since the development of discourses is essentially a product of collective human actions, the specific contexts must be acknowledged. Hence, learning and language use in mathematics will be analyzed within the social, cultural and cognitive practices of the particular learning context (Moschkovich, 2012).

Conclusion

Utilising Moschkovich's framework, this paper has provided an appraisal of the methodology and methods to be employed in the M²EID project, which is concerned with examining bilingual mathematics learners in situ. We assume that methodology is inclusive of both theory and methods. Accordingly, it is of importance to outline the underlying theoretical assumptions relating to the M²EID project, as well as how we plan on documenting, describing and explaining these phenomena. Hence, a core consideration for our project is what data to collect and how to collect such data. Therefore, a key aim of the M²EID research project is to evaluate the proposed methodology and methods in practice in order to ascertain their suitability for investigating bilingual mathematical learners in an educational context. In particular, the project will evaluate whether differences in languages, and their use, by bilingual mathematical learners have a differential impact upon cognitive mathematical processing, when engaged in conceptual mathematical activity.

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References

Asiala, M., Brown, A., D., D., Dubinsky, E., Mathews, D., & K., T. (1996). A Framework for Research and Curriculum Development in Undergraduate Mathematics Education. In J. Kaput, A. H. Schoenfeld, & E. Dubinsky (Eds.), *Research in Collegiate Mathematics Education, II* (pp. 1-32). Providence, Rhode Island: American Mathematical Society.

Barwell, R. (2016). Mathematics education, language and superdiversity. In A. Halai & P. Clarkson (Eds.), *Teaching and learning mathematics in multilingual classrooms: Issues for policy, practice and teacher education* (pp. 25-39). Rotterdam, The Netherlands: Sense.

Barwell, R., Barton, B., & Setati, M. (2007). Multilingual issues in mathematics education: Introduction *Educational Studies in Mathematics, 64*(2), 113-119.

Derry, S. J., Pea, R., Barron, B., Engle, R. A., Erickson, F., Goldman, R., Sherin, B. L. (2010). Conducting Video Research in the Learning Sciences: Guidance on Selection, Analysis, Technology, and Ethics. *Journal of the Learning Sciences, 19*(1), 3-53. doi:10.1080/10508400903452884

Desimone, L. M., & Carlson Le Floch, K. (2004). Are We Asking the Right Questions? Using Cognitive Interviews to Improve Surveys in Education Research. *Educational Evaluation and Policy Analysis, 26*(1), 1-22.

Gee, J. (1996). *Social linguistics and literacies: Ideology in discourses* (3rd ed.). London: The Falmer Press.

Grix, J. (2004). *The foundations of research*. London: PalgraveMacmillan.

Grosjean, F. (1999). Individual bilingualism. In B. Spolsky (Ed.), *Concise Encyclopedia of Educational Linguistics* (pp. 284-290). London: áElsevier.

Gutiérrez, K., & Rogoff, B. (2003). Cultural ways of learning: Individual traits or repertoires of practice? . *Educational Researcher, 32*(5), 19-25.

Kim, D. J., Ferrini-Mundy, J., & Sfard, A. (2012). How does language impact the learning of mathematics? Comparison of English and Korean speaking university students' discourses on infinity. *International Journal of Educational Research, 51-52*(3), 86-108.

Lave, J., & Wenger, E. (1991). *Situated Learning: Legitimate Peripheral Participation*. NewYork: Cambridge University Press.

Lemke, J. (1990). *Talking science*. Norwood, NJ: Ablex.

Moschkovich, J. (2002). A Situated and Sociocultural Perspective on Bilingual Mathematics Learners. *Mathematical Thinking and Learning, 4*(2-3), 189-212. doi:10.1207/S15327833MTL04023_5

Moschkovich, J. (2012). How equity concerns lead to attention to mathematical discourse. In B.Herbel-Eisenmann, J. Choppin, D.Wagner, & D.Pimm (Eds.), *Equity in discourse for mathematics–Theories, practices and policy* (Vol. Springer, pp. 89-105). NY: Springer.

Moschkovich, J. (2016). *Recommendations for research on language and learning mathematics*. Paper presented at the 13th International Congress on Mathematical Education, Hamburg.

Ní Ríordáin, M., & McCluskey, A. (2015). Bilingual mathematics learners, conceptual mathematical activity and the role of their languages. How best to investigate? In K. Krainer, & N. Vondrová (Eds). *Proceedings of the Ninth Conference of European Research in Mathematics Education*, Prague, Czech Republic (pp.1468-1474). Prague: Charles University in Prague, Faculty of Education and ERME.

Sfard, A. (2008). *Thinking as communicating: Human development, the growth of discourses, and mathematizing*. Cambridge, UK: Cambridge University Press.

Sfard, A. (2012). Introduction: Developing mathematical discourse – Some insights from communicational research. *International Journal of Educational Research, 51-52*(3), 1-9.

Vygotsky, L. S. (1962). *Thought and language*. Cambridge, MA: MIT Press.

Whorf, B. L. (1956). *Language, thought and reality*. Cambridge, Mass: M.I.T Press.