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Insights into transitions to, across and from university mathematics that arose through consideration of mathematical identity

Fionnán Howard¹, Siún Nic Mhuirí¹, and Maurice O'Reilly¹

¹Dublin City University, Institute of Education, Ireland, fionnan.howard@dcu.ie

In this paper, we present selected findings from the recently completed PhD study of the main author which is entitled Mathematical Identity of Science and Engineering students (MISE). The sample for the study included 32 students of science (including science education) and engineering from Dublin City University. A longitudinal research design facilitated the collection of data at the start, middle, and end of participants' programmes. Thus, the findings from this study of mathematical identity are expected to be of interest to those members of the INDRUM audience who are concerned with the lived experiences of students as they progress to, across and from university mathematics. For the purposes of this paper, participants from the science education and engineering programmes will be the focus of the discussion.

Keywords: Mathematical Identity, Transition to across and from university mathematics, Teaching and learning of mathematics in other disciplines, Pre-service teachers, Engineering.

INTRODUCTION

The aim of the MISE study was to explore the relationship of science (including science education) and engineering students with mathematics and to investigate how this relationship changed as they made the transition to university education (Howard, in press). Thus, the study addressed issues related to participants' navigation of Klein's first discontinuity (Klein, 1908/1939), meaning the transition from post-primary school to university, from first year their first year up until their final year. In this paper, we address the following research question: How does the relationship of these students with mathematics change over time?

Data was collected at three stages of participants' undergraduate studies, including in their fourth year as they prepared for the transition to their post-university careers. For those participants who entered the teaching profession, this transition is known as Klein's second discontinuity, which is more widely researched than the transition of engineering students to their workplace (Hausberger and Strømskag, 2022). We expect this study to be of interest to the INDRUM audience because the data reflect the lived experiences of students as they made the transition to, across and from university mathematics, and gives insight into the experiences that shaped the transition.

THEORETICAL BACKGROUND

In this section, mathematical identity is described firstly in the context of broad conceptualisations of the phenomenon that are common in the literature. Subsequently, some theoretical dimensions of mathematical identity proposed by Radovic et al. (2018) are discussed, and the approach taken in MISE is presented. Although a

definition of mathematical identity is offered in this section, the authors agree with those of a recent review of the area (Radovic et al., 2018), who concluded that knowledge of how each definition is conceptualised and operationalised is required to fully understand the theoretical stance of a mathematical identity study (p. 32).

In the most general terms, mathematical identity can be thought of as a student's relationship with mathematics, which evolves over time and guides the manner in which the student interacts with the subject. Grootenboer & Marshman (2016) explained the relationship as follows: "When students are learning mathematics they are simultaneously developing mathematical identities, and, their mathematical identities are enabling and constraining the way they are learning mathematics" (p. 116). Mathematical identity has been the subject of increased attention by researchers in recent years (Darragh, 2016, Figure 1). This has been attributed, in part, to the potential for identity to weave interrelated dimensions together, including "beliefs, values, attitudes, emotions, dispositions, cognition, abilities, skills and life histories" (Grootenboer & Marshman, 2016, pp. 27-28). Investigating the mathematical identity of pre-service teachers has proved popular because of the influence of teachers' identities on their teaching practice (Goldin et al., 2016, p. 14). For other students who study mathematics, identity can highlight issues that contribute to marginalisation, and thus influence whether students' continue, or not, to study and engage with mathematics (Solomon, 2007).

In their review of mathematics learner identity, Radovic et al. (2018) stressed that rather than choosing between a social or subjective emphasis, studies in identity often address the interaction or tension between the two (p. 27). The MISE study is best described as a narrative study which emphasises subjective aspects of identity (students' self-concept and their interpretation of their own experiences), but also allows the social aspects of identity to emerge through participants' narratives (how participants manoeuvre themselves within the possible identities which are made available to them) (Radovic et al., 2018, p. 29; Skott, 2019, p. 470). Mathematical identity was defined as the "multi-faceted relationship that an individual has with mathematics, including knowledge, experiences and perceptions of oneself and others" (Eaton & O'Reilly, 2013, p. 280). This definition allowed the pursuit of a narrative approach to identity because students' subjective self-concept as well as the social world around them were explicitly included in the definition. Consistent with a qualitative paradigm, rather than seeking to generalise the results of the study, one should consider whether the "thick description" provided by the author establishes trustworthiness and transferability of the results (Guba & Lincoln, 1985, pp. 124-5).

Connections between mathematical identity and transition

Although various definitions of identity are offered in the mathematics education literature, identity is usually positioned as a fluid and constantly renegotiated phenomenon, a so-called Meadean viewpoint (Darragh, 2016; Goldin et al., 2016). It has been argued that thinking of transitions in terms of identity may encourage students to see the challenges they have encountered as "troubles overcome in their rite of

passage” and “as an affirmation of who they are now” (Hernandez-Martinez et al., 2011, p. 128).

Narrative studies have often paid attention to points of change or transition which have appeared under various names: turning points, leading activities, critical events, core events/episodes. The use of such transition points for analysis is aided by participants telling a full sequential story of their experiences with mathematics. The popularity of autobiographical methods of data collection, often through interviews (Goldin et al., 2016), can be explained by recent research (past 20 years) into analytic approaches relying on points of change/transition, and more generally on the desire to infuse a temporal property into definitions of mathematical identity (past events are seen from the perspective of the present) (Kaasila, 2007, p. 212).

The longitudinal research design of MISE allowed the investigation of changes in mathematical identity over time and the experiences that affected students’ transition to, across and from university mathematics. In other words, mathematical identity can be seen as a lens through which we can investigate the lived experience of students as they navigate such transitions and put mathematics into action through teaching or industry placement (in science education and engineering programmes respectively).

METHODS

This longitudinal study comprised of three stages of data collection and analysis, involving thematic analysis of questionnaire and focus group data followed by a narrative analysis of interview data. The data was collected in students’ first year (semester II), third year (semester I), and fourth year (semester II). A summary of the research design is presented in Table 1.

Stage of data collection	Collection method	Sample size	Date collected	Type of analysis
Stage 1	Questionnaire (Q)	32	March 2018	Thematic analysis
Stage 2	Focus groups (FG)	6	October 2019	Thematic analysis
Stage 3	Interviews (I)	6	March 2021	Narrative analysis

Table 1: Stages of data collection and analysis in MISE.

The questionnaire for the study was adapted from that developed by Eaton et al. (2013) and consisted of three open-ended questions: a broad opening question, a follow-up question which included some prompts, and a final evaluative question (more details in Howard, 2023, pp. 260-262). The second stage of data collection consisted of two focus groups each with the aims to elaborate on the themes developed from the first stage, clarify some researcher interpretations, and examine changes in mathematical identity over time. Participants’ questionnaire and focus group responses were analysed through thematic analysis using inductive codes, which were derived from the data, and deductive codes which were developed from the literature and a pilot study (see Howard et al., 2019 for further details of this stage of data analysis).

The third stage of data collection consisted of narrative interviews in which participants were invited to recount their experiences of university mathematics year-by-year, consider and visualise the key events which influenced the journey, and compare their past and present mathematical identities with reference to their questionnaire responses from first year (more details in Howard, 2023, pp. 72-75). Narrative analysis of the data drew from an approach entitled “storying stories” (McCormack, 2000) to identify the stories that participants told about their experiences with mathematics and generate a personal narrative (or interpretive story) for each interview participant. The storying stories framework, along with the adaptations implemented in MISE, have been presented elsewhere by Howard et al. (2021). Thematic analysis of the first two stages of data collection permitted the development of themes which hold across the participants’ data, while narrative analysis of interview data allowed attention to the individual identities of a selection of participants through their personal narratives.

FINDINGS

In a previous conference publication, the authors of this paper have presented MISE participants’ resistance to teaching which promotes instrumental understanding of mathematics (Skemp, 1976, p. 20), and their stated desire to “understand” mathematics (Howard et al., 2022). In the remainder of this paper, we will discuss three findings related to participants’ transition to, across and from university mathematics, respectively. Quotations from students of science education are denoted SE01, SE02, etc. and those of engineering students are denoted EN01, EN02 etc. The suffixes Q, FG, and I indicate from which stage of data collection the quotation is drawn (Questionnaire, Focus Group, or Interview, respectively).

University mathematics requires hard work for everyone

Several MISE participants described struggling with mathematics for the first time at Senior Cycle in post-primary school (years 4-6) or in university, relying on the idea of “natural ability” to explain their, sometimes effortless, success in mathematics at earlier stages of schooling. SE01 described having a “mental block” against the “quite abstract” linear algebra module he encountered in second year at university: “[I] told myself that I couldn’t understand it ... it was kind of the first time that that happened ... even in school” (SE01_I). Another participant referred to the transition from post-primary school to university (third level): “When I entered third level, I expected I would be prepared from the leaving cert. However, I was very very wrong” (SE03_Q). In accordance with other research from the UK (Hernandez-Martinez et al., 2011), MISE participants who described mathematics as requiring minimal effort referred only to primary school or Junior Cycle in post-primary school (years 1-3):

“I didn’t study for the Junior Cert in Maths because it seemed common knowledge” (EN03_Q).

“[W]hen I entered senior cycle my relationship with maths completely changed. I went from being bored by how easy maths was to really struggling with it” (SE03_Q).

It appeared, therefore, that participants were acutely aware of the increased difficulty associated with Senior Cycle and university mathematics. In first year at university, many MISE participants indicated that they supported the belief that university mathematics requires hard work from everyone, regardless of any natural ability that may have given them an advantage in post-primary school. Furthermore, as the study progressed, participants' endorsement of this belief appeared to strengthen. In the focus groups, SE05 and SE04 agreed that outsiders often dismiss their hard work, believing that they must be effortlessly good at mathematics:

“People will say ‘oh you’re always good at maths’ sort of thing. We’ve all heard that probably, but they don’t say it about history or geography ... I just think you need to put in as much work to maths as you do for all the other subjects” (SE05_FG).

Solomon (2007) identified a dominant belief in the undergraduate community, that those who are good at mathematics are effortlessly successful, and that “you can either do it or you can’t” (p. 89), while Boaler (2016) reported that ““students who are successful through hard work often think that they are imposters” (p. 148). MISE participants rejected this viewpoint, and there was widespread agreement that while they might have been able to rely on natural ability before now, in university everyone needs to work hard to be successful in mathematics.

Collaboration

In the first stage of data collection, there were no indication that MISE participants collaborated with each other when studying university mathematics. Although it was not expected a priori that collaboration would be a main feature of participants' mathematical identity, it was decided to investigate how this evolved as participants moved further along the transition to university mathematics. In subsequent stages of data collection, the development of collaborative groups over time was revealed for both science education and engineering participants (Howard et al., 2022). Engineering participants described how they were routinely required to work as part of a team on group assignments and projects, and they established friend groups to work on assignments together in the library:

“Definitely with assignments. ... There's a particular few people in my friends group I'd say, that, we'd always kind of compare answers, just to see if we were getting them right. And if we got, had the same answers we knew we were right” (EN01_I).

EN02 agreed that “A lot of people formed friends so they could figure stuff out in the library” particularly for the engineering mathematics modules in first and second year: “Maths in particular was actually one that kind of brought the year together, I think” (EN02_I). EN02 elaborated that she sees the ability to collaborate in this manner as an essential quality of an engineer:

“Since first year, everyone has kind of said engineering is one of those degrees that you need to be able to talk to people about to actually pass and do well in. Because no one person has all the information. ... Then one maths question you end up under-

understanding a lot more than just one person standing up and kind of teaching you that way” (EN02_I).

Science education participants similarly described working together by the end of their programmes, but collaboration among the group seemed to develop more slowly compared to engineering participants. In the focus groups, SE01 and SE05 explained that they collaborated only a little with their classmates, particularly for one module which required them to answer mathematics questions through an automated online system. However, in the interviews in their fourth year, science education participants described that they “did the assignments together” (SE02_I) as well as practice exam papers, and even “just general, kind of keeping up with content of modules” (SE04_I). SE03 further explained that they would coordinate via text to study and attend, as a group, the Mathematics Learning Centre (MLC) in the university library.

Placement and work experience

For many students, placement and work experience offer them their first insight into the practical, day-to-day details of their future career opportunities, as was the case for two engineering and two science education interview participants in MISE (EN01, EN02 and SE01, SE02 respectively). These experiences informed students’ expectations about Klein’s second discontinuity: transition from university mathematics to the workplace. In the case of pre-service teachers, like those in the science education programme, this is also referred to as a “double discontinuity” as their workplace is a post-primary school (Klein, 1908/1939).

SE01 described a transformation of his perspective from studying a science programme and doing “maths for the sake of maths” with “no end in sight,” to a focussing on education and thinking “this is going to help me [in the classroom]” (SE01_I). He presented teaching placement in third year as a catalyst which “changed my thinking about the degree on a whole, as well as attitudes towards what I was doing” (SE01_I). By focussing on putting knowledge into practice through teaching placement, he realised that “some of the stuff you could nearly pick from the third-year modules and actually bring it into a fifth-year class” (SE01_I). SE02 similarly appreciated teaching placement because he could collaborate with, and learn from, teachers who were experienced in the practicalities of post-primary teaching, and appeared to believe that this provided an important platform for his development at that stage of his studies:

“The woman I’m working with she’s a year head, and she has what, 40 years of experience, and it really shows in the sense that, she’s old time right, she’s been there for a long time, she’s been there through way before Project Maths, then phasing in Project Maths. ... and her experience clearly shows” (SE02_I).

Perhaps influenced by teaching practice, SE02 expressed relief at completing his final pure mathematics module in second year (he did not specialise in mathematics subsequently) and appreciated later modules which focussed on pedagogical content knowledge, adding that it was “not even theoretical it’s very practical. That you can literally bring this into a class and use it if you need to” (SE02_I). He provided a second

year module (Teaching and assessing Junior Certificate mathematics) as an example: “They build upon the initial methods, and they get to the final method, which works amazing and you don't need to think about how you did it at the beginning ... that module is about building that back up” (SE02_I).

SE01 and SE02 disagreed with regard to the connections between their university programmes and their real-world practice during teaching placement. S01 appreciated the “deeper understanding” of Leaving Certificate mathematics that his early university modules provided and described that they were “given tools to verify or prove theorems” rather than practicing specific methods to answer particular questions, as was the case in his Leaving Certificate class. His descriptions of this deeper understanding resonated with Skemp’s characterisation of relational understanding as “knowing what to do and why” (Skemp, 1976, p. 20; cf. Howard et al., 2022). On the contrary, S02 did not choose mathematics as a specialty in third year, and appeared to position himself as a good teacher relative to his classmates precisely because he had a lesser knowledge of, and had remained untainted by, advanced mathematics. Instead, he believed that it was easier for him to “get back to basics” with the post-primary school mathematics curriculum:

“[I]t almost backfired, having us do maths in college, because we have gone so far, and I can only imagine how much like people who did maths as a subject [specialty] ... I wonder if they go back to teach will they struggle with it more than I would. Because I haven’t gone that far” (SE02_I).

Although both EN01 and EN02’s work placements were cancelled in third year due to the COVID-19 pandemic, they both appreciated the real-world experience they had encountered in summer internships. EN02 appreciated being given the responsibility and agency to design her own products and solutions to problems, using what she had seen in lectures:

“I think internships are a real good one for being like, oh ok, this that we’re seeing in college, it’s being applied. ... I was just presented with a problem, and they were like ‘fix it.’ What are you going to do to fix it? ... it was eye-opening to see that the stuff that you’re learning is actually, it’s in practice as well” (EN02_I).

Both engineering interview participants saw their summer internships as formative for judging the role of mathematics in their future careers, but, interestingly, neither felt that they used mathematics in their real-world practice, at least not directly. EN01 said “it is maths but it’s not what I would think of maths” and EN02 concurred that “[it’s] not just maths alone, definitely not.” EN02 clarified her comments with an example to explain why she felt that an engineer’s role in the workplace is more akin to what she called problem-solving:

“There was a machine that wasn’t working properly, and you had to understand like the actual mechanics of it to see what was happening, and it was that kind of problem solving. But I suppose like, the base layer of all of that stuff is maths” (EN02_I).

Goold (2015) showed that engineering students in another Irish institution perceived a gap between their academic learning and their workplace practice, which was attributed in part to the dominance of students' "objective" mathematical learning in class compared with the "subjective" mathematics competencies that are necessary in the workplace (p. 552). Indeed, we found that MISE participants' mathematical identities were built around absolutist views of mathematics, wherein mathematics is seen as pre-existing, immutable, and objectively true (Ernest, 1988), yet mostly believed that its purpose is realised through application to real-life situations.

CONCLUSION

This paper presented selected findings from the main author's PhD study into the mathematical identity of science (including science education) and engineering students in Dublin City University (Howard, 2023), and in particular, the research question "How does the relationship of these students with mathematics change over time?" In this paper, selected findings were presented in three parts, which addressed the transition to, across and from university mathematics, respectively.

Firstly, we found that participants believed that while they might have been able to rely on natural ability before now, in university everyone needs to work hard to be successful in mathematics. In part, this finding corroborates research from the UK which reported that while students felt that they could achieve good grades at GCSE level with little effort, A-level mathematics required more hard work and understanding (Hernandez-Martinez et al., 2011). For MISE participants, Leaving Certificate and University mathematics do not exhibit the same vulnerability as earlier stages of schooling, where a natural ability allows one to be successful in mathematics with less effort. Secondly, although in first year participants appeared to see mathematics as an individual endeavour, collaborative groups developed over time. This development seemed to occur more quickly for engineering students, who banded together to work on mathematics modules, group projects, and assignments.

Thirdly, science education participants appreciated the value of teaching placement for several reasons. For SE01, placement inspired a change in identity from a scientist-in-the-making to a teacher-in-the-making. He appreciated the "horizon knowledge" provided to him by his mathematics modules and the direct relevance to teaching practice of his education modules in later years. SE02 expressed a similar appreciation of modules which directly helped his classroom practice but explained that he considered it easier for him to "get back to basics" with Leaving Certificate mathematics precisely because he had not studied as much advanced mathematics as those who specialised in the subject. Absolutist views of mathematics were observed among MISE participants generally, and EN01 and EN02 appeared to present evidence that their real-world practice was closer to what they called "problem-solving" (applying or implementing mathematics) than to their absolutist conception of mathematics. This finding resonates with the pronounced divide between classroom mathematics and its real-world applications which was reported by another study in Ireland (Goold, 2015). Our analysis suggests that the nature of this divide may be

explained by students drawing a line between absolutist mathematics and their own conception of problem-solving in real-world engineering work. Such results are important because it is argued in the literature that structural engineers need to decide “how, when, and when not to use mathematics” (Gainsburg, 2007, p. 500), but that the in-school perception of mathematics as immutable might constrain the development of such a disposition among students.

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