Post-secondary students' enactment of identity in a programming and mathematics learning environment

Amanjot Toor, Joyce Mgombelo and Chantal Buteau

Brock University, Canada; atoor@brocku.ca; jmgombelo@brocku.ca; cbuteau@brocku.ca

This paper draws from year one of a 5-year research study that seeks to examine how post-secondary mathematics students learn to use programming as a computational thinking instrument for mathematics. It focuses on how post-secondary mathematics students' identities as mathematics learners are enacted as they engage in a programming-based mathematical investigations and applications learning environment. Specifically, the paper offers a discussion of a case of one student's enactment of his identity while simultaneously learning to program and to use it for this kind of mathematical work. This paper highlights the importance of identity in learning mathematics and its role in the development of productive dispositions in learning to program for mathematics investigation and modeling.

Keywords: post-secondary, identity, appropriation, community of practice.

Introduction

The Canadian federal government predicted that jobs in STEM fields will grow by 12% between 2013 and 2022, and that 35% of such jobs will be computer science-related ("Back to School", 2015). Few academic institutions attempt to prepare their graduates for the STEM workforce by integrating "Computational Thinking" (CT) in their programs. This integration of CT in STEM studies points to the need for research on what Healy and Kynigos (2010) describe as, "the complexities associated with the appropriation by the user of tools [such as programming]" (p. 66). This paper draws from year one of a five-year ongoing research study, funded by the Canadian Social Sciences and Humanities Research Council (SSHRC), entitled "Educating for the 21st century: Post-secondary students' learning to use computer programming for mathematical investigation, simulation, and real-world modeling" (referred to onward as 'progmatics'). The research addresses the need to better understand how post-secondary mathematics students come to appropriate programming as an instrument for mathematics investigations and applications. It is a naturalistic study that takes place in a sequence of three programming-based mathematics courses called Mathematics Integrated with Computers and Applications (MICA I–III), implemented in the mathematics department at a Canadian university in Ontario since 2001. In these courses, future mathematics teachers and undergraduate students majoring in mathematics learn to design, program, and use interactive computer environments to investigate mathematics conjectures, concepts, theorems, or real-world applications (Muller, Buteau, Ralph, & Mgombelo, 2009). The research project is framed by interrelated theories and concepts in mathematics education that articulate the complex mutual shaping of the learner (user) and artefact (programming) (Buteau, Muller, Mgombelo, & Sacristán, 2018), including Lave and Wenger's social theory of learning and theory of situated learning. Lave and Wenger's (1991) analysis of situated learning is embodied in their productive concept of "legitimate peripheral participation." Legitimate peripheral participation is supported by systems of relationship in community between newcomers and old-timers, as well as relationships with outside communities and with other newcomers. Legitimate peripheral participation offers a two-way bridge: between the development of knowledgeable skills and identity—the production of persons—and the production and reproduction of communities of practice. In this sense, the newcomers become old-timers through a social process of increasingly centripetal participation, which depends on legitimate access to ongoing community practice. This paper focuses on identity. We are interested in exploring how post-secondary students (newcomers) enact their identities during their process of appropriation of programming as a mathematical instrument as mathematicians (old-timers) would do, as they engage (i.e., legitimately peripherally participate) in 'progmatics' tasks. Specifically, the paper offers a preliminary discussion of student enactment of identity while learning 'progmatics' in a first year MICA course through a case of one student, Roy (pseudonym).

Conceptual Framework

In this paper, the concept of identity is further articulated from three perspectives, namely *self-efficacy, environment*, and *four faces of learner's identity,* developed in our previous work (Toor & Mgombelo, 2013); see Figure 1. Researchers in the field believe that self-efficacy is learned, and that self-efficacy expectations are acquired through various sources including accomplishment, vicarious learning, verbal persuasion, and emotional arousal (Bandura, 1977). Accomplishment as a source of self-efficacy refers to the way in which one's successful or unsuccessful experience on a given task increases or decreases the self-efficacy connected to that task. Another source, vicarious learning, can affect one's self-efficacy where one sees others—peers and classmates—succeed or fail on a given task, assessment, or course. Other sources of self-efficacy are verbal persuasion and emotional arousal. In verbal persuasion, beliefs about one's self are influenced by the messages conveyed by others. Emotional arousal refers to the stress and anxiety in a given task and its effect on self-efficacy.

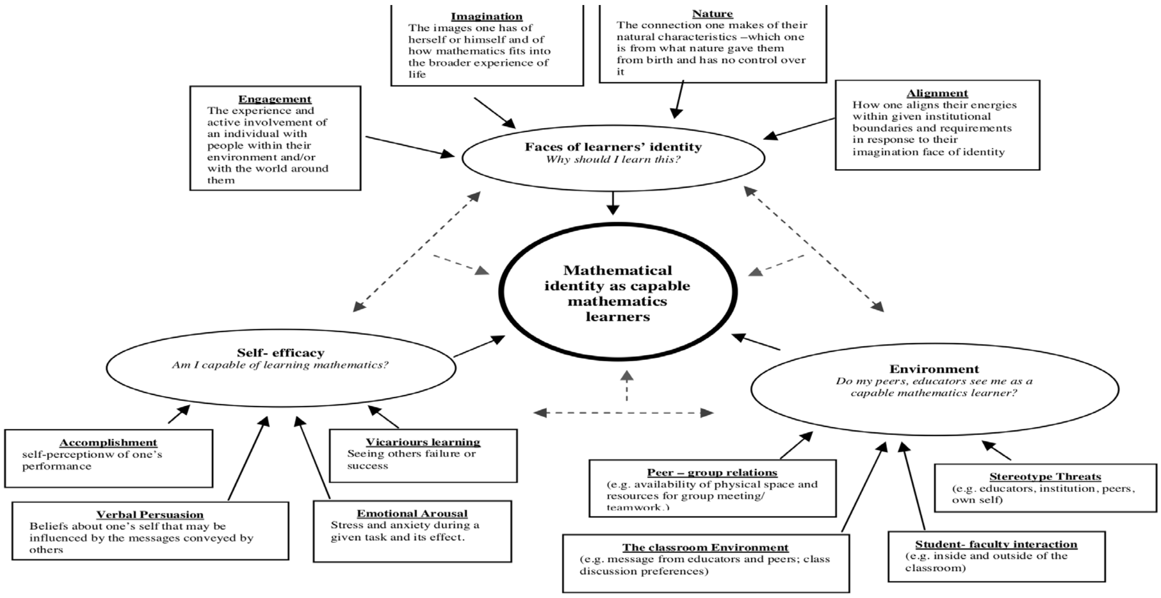

Figure 1: Conceptual framework: Mathematical identity as capable mathematics learners (Toor & Mgombelo, 2013, p. 2458)

Identity is influenced by one's environment. In other words, identity is greatly formed by individuals' relationships with others from the past to present, stretching into the future (Wenger, 1998). As individuals progress through the post-secondary level, they develop a stronger sense of who they are as mathematics learners through their mathematics experiences, such as in lectures, classrooms, and seminars, interactions with teachers and peers, and in relation to their anticipated future (Sfard & Prusack, 2005). In addition to self-efficacy and environment, mathematical identity can also be explored from Anderson's (2007) four faces of learning mathematics—*engagement*, *relativity/imagination*, *alignment*, and *nature*. Engagement looks at one's direct experience and active involvement of others within their environment and/or with the world around them. Relativity/imagination focuses on the images one has of him/herself and of how mathematics fits into the broader experience of life. The alignment face of learning mathematics refers to how one aligns their energies within given boundaries and requirements in response to their imagination face. Nature looks at the connection one makes of their natural characteristics. These characteristics refer to what nature provided one with from birth and over which one has no control.

Methodology

A mixed methodology approach is being used throughout the five-year ongoing study. The study uses an iterative design to refine and develop the research tools for yearly data collection and analysis. This paper draws from data that was collected in year one of the study, where six participants were recruited from the MICA I course. Data collected included each of the participants' four 'progmatics' project assignments (referred to as Exploratory Objects or EO), and reports, and semi-structured interviews with each of the participants after completing each of the four assignments (referred to as A1–A4). In addition, data collected included post-laboratory session reflections and a questionnaire. After each of the 10 weekly two-hour MICA lab sessions, participants recorded online their reflections on their learning during the lab session, L1–L10 (guiding questions were provided). All participants filled an online questionnaire (Q0) before the beginning of the MICA I course. This was followed by interviews where participants were asked to elaborate upon their questionnaire responses. The purpose of this questionnaire (and the first interview) is to serve as baseline information about participants' background of mathematics learning with technology.

Data analysis followed Cresswell's (2008) general principles of qualitative data analysis: preparing and organizing data, exploring data, describing and developing themes from the data. To begin the data analysis, codes were developed according to categories informed by our theoretical framework (Buteau et al., 2018). Each participant's qualitative data were coded individually by two researchers, who then jointly completed a thematic analysis of the data. Themes were consolidated among six participants' analyses, leading to the development of sixteen overall themes. These themes were further regrouped into five meta-themes, one of which was identity. The first author was assigned to analyze one of the six participants' data, which was later further analyzed in order to explore the identity meta-theme specifically through the lenses of self-efficacy, environment, and four faces (see Figure 1) of learners. In this paper, we present and discuss the findings of the case of this participant, Roy's, enactment of identity in the MICA I course.

Findings and Discussion

Description of the case: Roy

Roy was in his first year of the Bachelor of Science in Mathematics program when he enrolled in MICA I. Prior to MICA I, Roy's experience with programming included programming in Julia (just the basics), R (just the basics), Maple, Wolfram, and Python, as well as HTML. In the first questionnaire (Q0), Roy noted that he did not have any prior knowledge of Vb.net (programming language used in MICA I), as he had, "never really heard about it" (Q0, 4). When asked to complete a statement about his feelings regarding the fact that the significant component in MICA I is computer programming, Roy responded "Very confident" (Q0, 5). When asked for his reason for his response, Roy said, "[m]ost languages have the same components just different syntax" (Q0, 5). Roy indicated that learning to program for mathematical activities is very useful because "it can be used in almost every area of science or just for figuring out proof that would take years for a human mind to do" (Q0, 6). According to Roy, students learn mathematics by learning how to derive the "equations of the proof and learning how to use the equations". He personally learns mathematics by, "teaching it to someone else" (Q0, 9). When asked, "What does 'doing mathematics' mean to you?", he responded, "It means solving a problem in the most logical way" (Q0, 10).

As part of the first MICA I assignment (A1), Roy was asked to select or state a conjecture, and to create and use his EO to explore it. When asked to describe his conjecture, Roy said:

> Opperman's conjecture, [for every integer $x > 1$, there is at least one prime number between $x\ (x - 1)$ and x^2, and at least another prime between x^2 and $x\ (x + 1)$] I did and that has to do with every real number greater than two…if you square it and then you minus that number and plus that number, in between those two zones there is at least one prime. (A1, 3)

In the second assignment, Roy implemented the RSA encryption algorithm, including encoding, decoding, and randomly generating keys. In the third assignment, Roy created an EO to explore the dynamical system based on a cubic (two parameters involved) and describe its behaviour. For the fourth EO, students choose a topic of their interest and work individually or in groups of two or three. Roy worked with a partner on the idea of trying to predict human population.

Roy's enactment of identity

Analysis of data from Roy indicates two ways in which Roy enacted his identity while learning 'progmatics' in MICA I: through ideal images and through his direct personal experiences (Toor, 2013). Roy describes his perception of an ideal image of a mathematics learner in MICA I by describing his experiences in other non-MICA courses. When asked about his plan regarding taking the MICA II course, he responded that he was not planning to continue with MICA II as he did not find it engaging. When asked about the reason why he thought the course was not engaging, he responded:

> With my straight math course, there were some things…Like being able to prove the volume of a sphere just through calculus. I find that very interesting cause then it's just like something you show people or… I found that interesting, whereas I didn't have that feeling with MICA I. (A4, 31)

It is clear from above that Roy's idea of a learner in MICA I is based on an ideal image of a learner in other non-MICA traditional courses, such as calculus. This ideal image of a learner in traditional courses manifests in a tension Roy experiences between how MICA courses are designed to engage students and how he perceives an ideal image of a learner in non-MICA courses. In Lab 10 of the course, students were asked to use their programs to explore the dynamical system based on the logistic function. When asked to reflect on his experience in the lab session, he noted:

> The last class covered all of what I needed to start my project. This class didn't do much for me. This class should have been more about the assignment. I got some help with my project that I had almost finished but at times they refused to help since they were supposed to focus on the program we had to make to get 5% on the assignment. I understood the concept of a dynamical system but I never got why it was important. (L8–10, 10)

It is interesting to note that Roy did not take the opportunity to learn through inquiry. He struggles with the learning experience in the lab session because his ideal image informs him that, as a learner, the important thing is to complete the assignment and get a good grade.

Roy's self-efficacy

Roy's self-efficacy in terms of accomplishment in the MICA I course is influenced by his perception of his mathematics and programming ability. In terms of mathematics ability, Roy seems to perceive himself as someone who is better than his peers: "I wouldn't ask my peers, normally..., [I'm] ahead of them" (A3, 5.3). This perception seems to show Roy's hesitance to work or collaborate with peers. In addition, Roy's perception of his ability in mathematics separates his ability in mathematics and his ability in programming when he encounters a difficulty in a 'progmatics' task. For example, he states:

> The first two codes we had to do were easy, the third left out too much information. The lab was to help us understand RSA and by the end I still didn't have a strong understanding of it. I didn't like that we were told to get into groups to test out our program...The most challenging part was understanding the RSA encryption. When the math is broken into parts none of it was very challenging or hard to understand. It was the major concept I still didn't get at the end. (L5–7, 6)

The experience of mastery influences one's perception of one's ability, where success and/or failure on a task have a direct impact (Bandura, 1977). Roy's failure to deal with the third part of the lab due to the challenge it presented may influence his perception of his ability in programming. This part of Roy's self-efficacy in terms of accomplishment is also connected with his self-efficacy in terms of vicarious learning. On one hand, Roy perceives his mathematics ability as ahead of his peers, but on the other hand he perceives others' programming ability as more advanced than his own. In the interview, he said: No, it only worked…mine only works with numbers. Um, uh, the girl that I was sitting next to the previous one she did uh numbers she's like super advanced in computer science though (A2, 30). In other words, Roy's vicarious learning, a part of his self-efficacy, consists of him comparing his performance with others' and reflecting on his ability in mathematics and programming. Roy's self- efficacy in terms of emotional arousal could be seen in the choices that he made, the effort he expended, the perseverance he exerted in the face of difficulties, and the thought patterns and emotional reactions he experienced in MICA I tasks. When he was asked about why he was not planning to take MICA II, Roy said:

> I like the in-class learning about the RSA and how different number theories, chaos theory and that kind of stuff. I didn't like doing the programming. Whenever I got an assignment, I did not find it fun or engaging to do, which I found in my math class. I really like doing the equations in the programming or in chemistry. I like doing that stuff but in this I didn't have much enjoyment in doing the programming. Whenever I got a problem…it just didn't…it just sucks. (A4, 29)

When Roy was given the freedom to select the topic for a task in the final assignment, he displayed excitement and satisfaction, which in turn allowed him to invest himself emotionally with the learning goal of the task. When asked about the outcomes of his final project, Roy said: "Really awesome. It was cool that we actually got the same result [as the World Infant Mortality Rate], I thought."

Roy's environment

One's environment is an essential element in building the identity of an individual as a member of the environment. Solomon, Croft and Duncan (2010) claim that peer-group relations play an important role in the educational success of the individual at the post-secondary mathematics level. As we have previously discussed, Roy seems to not like to ask his peers for help. This could be due to the fact that he views himself as "ahead" of others. Interestingly, Roy seems to be okay supporting others: "I did help another person with his conjecture by letting him see my code" (A1, 7). Also, he seemed to find it frustrating to work collaboratively with his partner in the final assignment. When asked about what was frustrating about working on his project, Roy answered:

> Working with my partner, I guess. He wasn't a very independent partner, so he wanted us to sit beside each other while we do the project. I was busy doing other stuff, so I ended up doing the first part of the project but then he still wants to do the write up, which the write up only took two hours and I ended up doing the write up myself as well. (A4, 21)

Roy's relationship with faculty consisted of getting help from his professor and/or TA whenever he got stuck with a task.

Roy's four faces of learning mathematics

Identity in terms of each of the four faces of leaning mathematics exists as a way in which one comes to understand their practices and membership within the community of mathematics learners (Anderson, 2007). Roy's enactment of identity in the MICA I course seems to be strongly influenced by his engagement. Anderson (2007) states; "much of what students know about learning mathematics comes from their engagement in mathematics classrooms" (p. 8). This enactment of Roy's identity in terms of the engagement face could be seen in the tension that Roy experienced in terms of the timing of when a task was assigned, which did not align with the timing of when some of the concepts needed to complete the task were taught in the class (even though they were eventually taught before the deadline): I had to do some research because in class we didn't, there was some of the stuff that were key concepts that we didn't actually, finish [before reading week] … one of the last concepts before the due date, was then given it was very key. (A2, 2). It seems that Roy has developed this identity from his experience of engagement in many mathematics classrooms where assignments are normally given after the required concepts or skills are covered. Another way Roy's identity in terms of his engagement with the MICA I course could be seen is in his perception of the computer language used in the tasks:

> The program language itself isn't very good. [Visual] Basic [is] pretty outdated—more or less obsolete. The only thing that [Visual] basic is used for is functions in Excel, like doing macros, which it's useful but it is not. It's getting outdated so I think the only part that was useful for me learning was the math that was taught in class and a little bit of how to implement that math into programming. But it's not going to be super useful in a job because I am not going to use [Visual] basic after I learn an entirely different programming language. (A4, 25)

This perception of the programming language seems to lead Roy to not identify with the MICA I environment and come to see himself as only marginally part of the MICA I community. In fact, when he was asked if he would take MICA II, he said no. Additionally, Roy's engagement with the programming language displays his identity in terms of his relativity/imagination face when he envisions how the computer language fits in with his future career goals. Further, when asked if he thought that doing mathematics in a programming setting was beneficial, Roy responded:

> I think it would have to be more complex programming like when we were using Maple because that already has built-in functions, whereas this one, it just all, you have to do every bit of math yourself. When even today's time programming, you have to use other people's work to do more complex work. I think that eventually you would have to get to it. I think it's good for teachers but like for pure math students, that I don't think I got much out of it. (A4, 24)

This shows Roy's identity in terms of the alignment face of learning mathematics, where he chooses to align his energy toward a "progmatics" task that displays "more complex work" based on his perception of himself as a pure mathematics student. It is interesting to note that Roy's identity in terms of the nature face does not come forward in any of his interviews.

Conclusion

This paper draws from research that addresses the need to better understand how post-secondary mathematics students come to appropriate programming as an instrument for mathematics investigations and applications. Papert (1980) proposes that every learner should program computers for personalizing learning and knowledge. He notes that at the heart of learning is 'appropriation' in the sense of making it 'yours.' This idea of taking the learning, and integrating it into one's way of being, thinking, and seeing necessitates an exploration of how one's identity plays a role in students' appropriation of programming (in the sense of transforming it as an instrument) for mathematics inquiry. This paper provides a beginning of this kind of exploration through a preliminary analysis of a case of one participant, Roy's enactment of identity in a first year MICA course. Roy came into MICA I with a perception of a learner in MICA I course based on his ideal image of a learner in traditional mathematics courses. Consequently, Roy's perception of this ideal image created a tension between the creative, inquiry-based expectations in MICA and his expectations of what the course should be. His perception of learning mathematics created a tension between his learning goals and the learning goals of MICA I—which are to learn to design, program, and use interactive computer environments to investigate mathematics conjectures, concepts, theorems, or real-world applications. This paper highlights the idea that learning to program for mathematics investigation and modeling requires not just developing skills and knowledge, but also developing an identity of a learner who engages in the inquiry-based tasks (peripherally) as mathematicians would do.

References

Anderson, R. (2007). Being a mathematics learner: Four faces of identity. *The Mathematics Educator, 17*, 7–14.

Back to school: Canada lagging in push to teach kids computer coding (2015, September 1), CBC News. Retrieved from http://www.cbc.ca/m/news/topstories/back-to-school-canada-lagging-in-push-to-teach-kids-computer-coding-1.3185926

Bandura, A. (1977). Self-efficacy: Toward a unifying theory of behavioral change. *Psychological Review, 84*, 191–215.

Buteau, C., Muller, E., Mgombelo, J., & Sacristán, A. (2018). Computational thinking in university mathematics education: A theoretical framework. *Proceedings of Research in Undergraduate Mathematics Education conference*, San Diego, CA.

Creswell, J. W. (2008). *Education research: Planning, conducting, and evaluating qualitative and qualitative research (3rd ed.).* NJ: Pearson Education.

Healy, L., & Kynigos, C. (2010). Charting the microworld territory over time: Design and construction in mathematics education. *ZDM*, *42*(1), 63–76.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation.* New York, NY: Cambridge University Press.

Muller, E., Buteau, C., Ralph, B., & Mgombelo, J. (2009). Learning mathematics through the design and implementation of exploratory and learning objects. *International Journal for Technology in Mathematics Education, 63*(2), 63–73.

Papert, S. (1980). *Mindstorms: Children, computers, and powerful ideas.* New York, NY: Basic Books.

Toor, A., & Mgombelo, J. (2013). Undergraduate students' perceptions of themselves as capable mathematics learners. In B. Ubuz, C. Haser & M.A. Mariotti (Eds.), *Proceedings of the Eighth Congress of the European Mathematical Society for Research in Mathematics Education* (pp. 2456–2465). Ankara, Turkey: Middle East Technical University and ERME.

Sfard, A., & Prusak, A. (2005). Telling identities: In search of an analytic tool for investigating learning as a culturally shaped activity. *Educational Researcher*, *34*(4), 14–22.

Solomon, Y., Croft, T., & Duncan, L. (2010). Safety in numbers: Mathematics support centres and their derivatives as social learning spaces. *Studies in Higher Education, 35*(4), 421–431.

Wenger, E. (1998). *Communities of practice: Learning, meaning, and identity.* Cambridge, UK: Cambridge University Press.