Undergraduate students' mindsets in a computer programming mathematical learning environment

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This paper focuses on how undergraduate students' mindsets are enacted and constructed in a programming and mathematics learning environment. This research draws from year one of a five-year study entitled "Educating for the 21st Century: Post-graduate Students Learning Progmatics (Computer Programming for Mathematical Investigation, Simulation, and Real-world Modeling), which addresses the need to empower students within the STEM field. A narrative approach is employed to present findings from two students, Sydney and Jim (pseudonyms), followed by a discussion on their enacted mindsets during a first-year 'progmatics' course.

Keywords: Mindset. University mathematics education. Programming. Identity.

Introduction

Jobs in the STEM field are on the increase. A major percentage of those jobs require computer science-related knowledge (CBC News, 2015). However, students in undergraduate computer science programs often feel defeated, having little confidence in their ability because of obstacles they encounter that are inherent to programming (Cutts, Draper, O'Donnell & Saffrey, 2010; Murphy & Thomas; 2008). Moreover, many mathematics students avoid engaging in mathematical tasks that require reasoning, exhibiting phobias and anxiety in extreme cases, because they perceive these tasks as difficult (Boaler, 2016). The pressing need to educate students in STEM, combined with students' often negative responses to learning programing and mathematics, necessitate inquiry of how students perceive their intelligence and abilities as they learn these disciplines.

This paper draws from year one of a five-year study funded by the Canadian Social Sciences and Humanities Research Council (SSHRC) entitled "*Educating for the 21st Century: Post-graduate Students Learning Progmatics (Computer Programming for Mathematical Investigation, Simulation, and Real-world Modeling*). This study addresses the need to empower students within the STEM field and to better understand the complexities involved when students learn to appropriate tools such as 'progmatics'. The study focuses on the question of how mathematics students come to appropriate programming as a computational thinking instrument in the context of three 'progmatics'-focused undergraduate mathematics courses, called Mathematics Integrated with Computers and Applications (MICA). This course sequence teaches students the fundamentals of programming for conducting mathematical explorations and applications. Analysis of data gathered within this study provides a suitable opportunity to investigate students' mindsets as they grapple with the complexities of a 'progmatics' learning environment. Specifically, this paper will focus on how students' mindsets are enacted and constructed while learning 'progmatics' during the first MICA course. To achieve this aim, the narratives of two students, Sydney and Jim (pseudonyms), will be explored.

Mindset refers to the brain's potential to formulate perceptions, affecting attitude and achievement. Mindset was first introduced in educational research in the 1920s but in recent years, Carol Dweck's work on oppositional theories of growth and fixed mindsets has popularized mindset (Popan, 2016).

Dweck's notion of growth mindset has been applied in various contexts. Cutts et al. (2010) assert that the barrage of obstacles faced by students during their undergraduate programs promote fixed mindset beliefs. Furthermore, Murphy and Thomas (2008) contend that while self-theories are applicable in all disciplines, the way students perceive their abilities may be more significant in computer science education, particularly in computer programming, due to inherent challenges such as contending with elusive and puzzling syntax and runtime errors. Based on these arguments regarding the significance of self-theories to mathematics and programming, a growth mindset may be even more important for learning mathematics within a programming environment, given the added difficulties stemming from both disciplines. Our study adds to other mindset research focusing on mathematics or programming as it involves not only one aspect (programming or mathematics), but the combination of both disciplines.

Conceptual Framework

Our view of learning relies on Lave and Wenger's (1991) work on communities of practice. Lave and Wenger (1991) contend that learning takes place relative to the context in which it is learned through legitimate peripheral participation, whereby *newcomers* become *oldtimers* by authentically taking part in a seamless process of gradually increasing responsibilities. The newcomer, starting at the periphery, may initially observe, but contributes within a community of practice almost immediately by doing small tasks which are progressively increased until he/she becomes an oldtimer. For Lave and Wenger (1991), the process of becoming a legitimate member of a community involves not just change in knowledgeable skill, but also a change in identity. Wenger (1998) defines this identity as "a layering of events of participation and reification by which our experience and its social interpretation inform each other" (p. 151). This definition implies that a change in mindset results from a change in identity because individuals' perceptions of their own abilities is shaped as they experience their sociocultural environment. In this sense, individual stories and narrative approach are relevant in inquiry on one's experienced mindsets. Storying or constructing narratives are common means utilized by humans to make sense of the myriad of complex experiences they encounter; contributing to the formation of their identity (McAdams, 2008), and by extension, their mindset. A narrative approach is a growing trend in research relating to identity and, in general, educational research (McAdams, 2008).

Dweck (2010) describes two mindsets, fixed or growth, that influence student performance in two distinct ways. Students with a fixed mindset perceive their abilities as stable traits, believing that they have a set capacity to be successful that cannot be changed. Students with a growth mindset, however, understand that with effort and perseverance, their abilities can be improved. Solomon (2007) asserts that a students' mathematical mindset plays a key role in developing their identity. Mindset is also a critical factor in determining a student's attitude towards learning and their level of achievement (Boaler, 2016; Dweck, 2015; Murphy & Thomas, 2008). Dweck (2010) claims that in general, individuals with a fixed mindset avoid challenges, give up easily, do not value effort, dismiss positive feedback, and are threatened by others' success. In contrast, individuals with growth mindset flourish on challenges, remain persistent despite setbacks, value effort as a path to mastery, use criticisms to improve learning, and use others' success as motivation and a source of valuable lessons. Furthermore, Murphy & Thomas (2008) note that as it relates to challenges, students with fixed mindsets focus on performance goals by opting for easier tasks as their ultimate objective is to display their ability. In contrast, students with growth mindsets focused on learning goals and are not deterred by difficult tasks or by making mistakes, in fact, they will seek out opportunities for challenge (Dweck, 2010). Importantly, a growth mindset goes beyond effort, referring to the extent to which students use innovative strategies and seek help when they are stuck (Dweck, 2015).

Methodology

Throughout the duration of the larger five-year study, a mixed-methodology approach will be utilized. An iterative design approach (Plomp & Nieveen, 2013) will be employed to refine and develop the research tools for yearly data collection and analysis. The study employs a naturalistic case study approach to examine how students' instrumental genesis of programming for mathematics develops in the MICA course sequence. This research takes places in the mathematics department of a university in Ontario, Canada. The present paper draws from data gathered in year one of the larger study, where six participants in the MICA I course were recruited voluntarily. Data gathered included each participant's four 'progmatics' projects, including both their program (called exploratory objects (EOs)) and assignment report, and semi-structured individual interviews that were conducted as a follow up to each assignment. Interview prompts were informed by a model of a student's developmental process in designing, programming and using a mathematics EO (Buteau & Muller, 2010). Data also included online post-laboratory session reflections, where after each of the ten weekly two-hour MICA lab sessions, participants recorded reflections on their learning during the lab as prompted by guiding questions. Finally, all participants completed an online questionnaire before beginning the MICA I course, followed by individual interviews where participants were asked to elaborate on their questionnaire responses. The purpose of the questionnaire and follow-up interview was to uncover baseline information about participants' background experiences in learning mathematics with technology, as well as their early sentiments towards the MICA I course.

Analysis of the study's qualitative data followed Creswell's (2008) general principles of qualitative data analysis: preparing and organizing data, exploring data, and describing and developing themes from the data. To begin the analysis, codes were developed according to categories informed by the theoretical framework (Buteau, Muller, Mgombelo & Sacristán, 2018) and related literature, with additional codes emerging during the analysis process. Each participant's qualitative data was coded individually by two researchers, who then jointly completed a thematic analysis of the data. Themes were consolidated among the six participants' analyses, leading to the development of sixteen overall themes. These themes were further regrouped into five meta-themes. In this paper, we focus on the meta-theme of identity and its subthemes of affect and students' perceptions of learning mathematics.

Findings and Discussion

In this section, we present and discuss findings from two participants, Jim and Sydney (pseudonyms).. We present two narratives of the participants' individual enactment of mindsets upon entering and during the MICA I course, followed by a comparative discussion.

Sydney's Story

With no prior programming experience, Sydney approached the MICA I course with feelings of nervousness and apprehension. In the first MICA I labs, her anxious sentiments were somewhat alleviated through interactions with her instructor, helping her to grasp basic programming concepts. She faced some challenges in the first assignment (EO1), where students were tasked with creating a program to explore a mathematical conjecture of their choosing. Sydney posed a conjecture that was a minor modification of one previously covered in the MICA I labs. She kept her program relatively simple, ensuring that she did not go "beyond [her] limits" during the coding process. The greatest obstacle she faced in completing this task was debugging her code, but with the help of a more experienced peer she created a functioning program. Sydney felt relieved that she was able to successfully complete the assignment, but was still hesitant about her programming ability and hoped that the next assignment would be easier.

Sydney experienced varying levels of success and confidence throughout the remainder of the MICA I course. The second assignment, involving the design of a program about RSA encryption, presented many challenges for Sydney. She was frustrated that she was unable to create a functioning program, compounded by the fact that she did not have enough time to seek help from a peer or an instructor before the submission deadline. Sydney felt discouraged by this assignment, claiming that she was unsure she could achieve success in the MICA program. By consulting her notes from lab and collaborating with a peer, she was able to complete the final assignments successfully and gained some confidence in her programming ability. However, Sydney ended the course hesitant about MICA II, feeling significant doubts toward her ability to learn the new programming material.

Jim's Story

Jim began the MICA I course with a general disposition of curiosity and excitement. Though Jim had limited formal experience in programming, he had been raised by a mother employed in the computer science field and was often given the opportunity to experiment with technologies throughout his childhood. This informal understanding of programming helped Jim to feel excited at the opportunity to formally learn to code. Jim's openness towards learning programming was also reflected in his greater attitude towards learning mathematics. He believes that individuals must keep an open mind towards their mathematical abilities to avoid feeling prematurely defeated and be able to persevere through challenges.

For EO1, Jim first developed a conjecture by creatively representing prime numbers and exploring patterns amongst them. Unfortunately, Jim was unable to pursue this ambitious idea within the scope of the course and his basic programming knowledge, eventually settling for a doable yet challenging alternative conjecture, that of Pólya conjecture suggested by the course instructor. However, he expressed the desire to follow up on his conjecture, feeling confident that he could develop a program to explore it when he has greater knowledge of programming. Once his program was complete, he was pleased to see it running, but stated that he always had faith it would work. Jim encountered challenges while completing the remaining assignments and coursework but did not seem bothered by these setbacks. When Jim was limited by his beginner level knowledge of programming, he would conduct research or try to find an alternative method of solving his problems. He ended the course understanding the advantages of working within a ‘progmatics’ learning environment, only feeling disappointed that he was not able to do more.

Comparison between two enactments of mindsets

Dweck (2015) notes that mindset is a critical factor in determining students’ attitudes towards learning and their level of achievement. Analysis of both Sydney’s and Jim’s accounts of their experiences provide evidence of their mindset upon entering and throughout the course. The following quotes, taken from Sydney’s and Jim’s baseline questionnaires, provide insight into their initial sentiments and mindsets towards learning at the beginning of MICA I:

Question: This MATH 1P40 [MICA I] course has a significant component of (computer) programming. This makes me feel…

Sydney: Nervous

Jim: Very confident

Question: Because:

Sydney: I barely have any knowledge in programming

Jim: If I'm finally going to get a chance to learn this stuff, I'm all for it. I've never had problems in the past, and if anything, I was annoyed that I wasn't being taught enough.

Here, Jim describes his confidence and excitement about entering the course, explaining how he looked forward to learning the programming content. In contrast, however, Sydney highlights her nervousness resulting from her lack of programming knowledge, suggesting her initial confidence level in the MICA program was low. Notably, although Jim also had limited programming knowledge, it did not cause him to feel this same apprehension. This could indicate that he was open to challenges, possessing characteristics of a growth mindset as Dweck (2010) asserts.

There are several notable elements regarding both students’ enacted mindsets as they experienced “progmatics” over the semester, first in terms of how they approached challenges. Throughout the course, Sydney demonstrates a desire to avoid tasks that present significant challenge. For EO1, Sydney chose a conjecture that was quite similar to a conjecture covered in one of the lab sessions (see Sydney’s Story). In her EO1 follow-up interview, she explains that she did not investigate a more creative conjecture in order to avoid going “beyond [her] limits” with the coding. She also expressed that she was looking forward to EO2 due to its more specific nature, stating, “I hope it’s going to be easy”. Later in the course, Sydney noted that she enjoyed the graphing component of her EO3 because “it wasn’t that tough”.

Unlike Sydney, Jim was not afraid of taking on challenges during his time in MICA I. When asked how he selected his conjecture for his EO1, Jim explained how he tried to develop a complex conjecture by himself through creatively exploring a variety of mathematical concepts. Though his mathematical ideas could not be explored with his startup programing knowledge, and he ultimately explored a more feasible (yet challenging) conjecture as advised by his professor, he expressed interest in pursuing his ideas in the future. In his EO1 follow-up interview, Jim reflected on his initial idea, stating, “I don’t think it is as hard as everyone makes it out to be, it just requires a bit of a different way of thinking". Similarly, in Jim's final assignment, he again expressed the desire to go beyond his level when developing his question and was disappointed that he did not yet have the required knowledge of programming to do more with his project.

Students' approaches to challenges provide a strong indication of their mindset towards both learning and intelligence. The fixed mindset approach was consistently evident in Sydney's data, as her actions and perspective routinely demonstrate how she chose to explore simpler problems and favoured assignments that were seemingly easier. In contrast, Jim routinely attempted to challenge himself when developing conjectures and mathematical questions, demonstrating a growth mindset approach.

A second notable point about Sydney's and Jim's enacted mindsets is how they overcame the challenges they encountered and the effects of these challenges on their attitudes towards their abilities. While Sydney was able to overcome difficulties in her first assignment with the help of a peer, her EO2 presented much more significant issues. Because of external time constraints, Sydney was unable to seek help from a peer or the course instructor, and was frustrated when trying to get her program to work. Due to her inability to create a functioning program, Sydney doubts her ability to continue in the MICA program, stating, "if [my EO2 program] goes poorly I don't think I want to continue". This doubt persisted until the end of the semester, despite greater success in her EO3 and EO4 tasks. When asked how she felt about taking the MICA II course next year, she responds, "I'm still hesitant… about the new things we will learn and if I can manage to understand them".

Jim's approach to setbacks was markedly different from Sydney's. Throughout the course, it seemed that he used challenges to improve his strategies for future assignments instead of allowing them to diminish his confidence. Though he experienced setbacks in his EO2, Jim reflected on this process and how those challenges helped him improve. When he was asked in his EO3 follow-up interview if he would do anything differently, he expressed the following:

> Jim: I feel like in assignment two… halfway through I had stopped planning and kind of regretted that afterwards, as you kind of get lost in the code but… for this [EO3] project I planned fairly well, I didn't get lost… I'm pretty happy with the way I did it.

In EO3, Jim had to do a fair amount of debugging to get his program to work, but he did not seem frustrated and used clear strategies to get his program to work. When asked about the obstacles he faced in EO3, Jim stated, "with computer programming, you accept that you are going to run into some bugs, which is why you test it at different stages". Jim maintained this attitude when completing his final assignment. When asked about debugging his program in the EO4 follow-up interview, he responded, "It didn't work for a bit. I went back and looked at it and realized that I had forgotten something, but nothing really significant". At the end of the course, Jim did not face the same doubts as Sydney towards his ability to be successful in MICA II. When asked about moving forward, he claimed, "I think it would be a reasonable course to take next year".

This approach to assignments and challenges is linked to two broader themes of mindset noted by research in a variety of contexts (Boaler, 2016; Murphy & Thomas, 2008; Cutts et al., 2010), underscoring much of Dweck's work. These contrasting mindset themes are labelled as the helpless pattern and the mastery-oriented pattern. Students that view intelligence as fixed are more likely to demonstrate a helpless response to significant challenges; whereas students with a growth mindset display a mastery-oriented response to setbacks. Students who exhibit the helpless pattern are easily defeated when faced with challenges, measuring their capability against the obstacles and significantly doubting their ability to succeed when faced with a difficult task. Conversely, students who display mastery-oriented responses remain motivated through setbacks, persevering through the problem and overcoming it by applying innovative strategies (Diener & Dweck, 1978). Sydney's and Jim's responses to the challenges they face could give further insight into how these patterns are enacted within a 'progmatics' learning environment. Sydney's response to challenges shows aspects of the helpless orientation stemming from her fixed mindset, as she is quickly overcome with doubt and discouraged by setbacks. In contrast, Jim was not deterred by mistakes and setbacks, which he perceived as a natural part of programming. Jim's ability to persevere and flourish when faced with obstacles illustrates a mastery-oriented response in accordance with his growth mindset.

Conclusion

This paper highlighted the enactment of two students' mindsets in the context of an introductory 'progmatics'-focused undergraduate course. Because of the inherent challenges in learning programming and necessity of resilience in the field of mathematics, having a growth mindset holds particular importance in a computer programming mathematical learning environment such as MICA I. The assignments and reflections of two MICA I students, Sydney and Jim, were compared to illustrate their differing mindsets towards their intelligence as they engage with 'progmatics' through legitimate peripheral participation (Lave & Wenger, 1991). As a result of their differing mindsets, Sydney finished the course feeling doubtful towards her ability to be successful in MICA II, while Jim maintained his confidence and expressed the desire to further develop his programs. Considering the important role played by programming and mathematics in STEM jobs, it is critical that students are encouraged to pursue and achieve success in these fields. Our work provides a beginning of how we can explore students' mindsets as they learn using programming for mathematics investigations and applications.

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