University Math Students Learning to Use Programming for Math Inquiries: What Students are Most Proud Of and Why

CTmathU
Computational Thinking in University Mathematics

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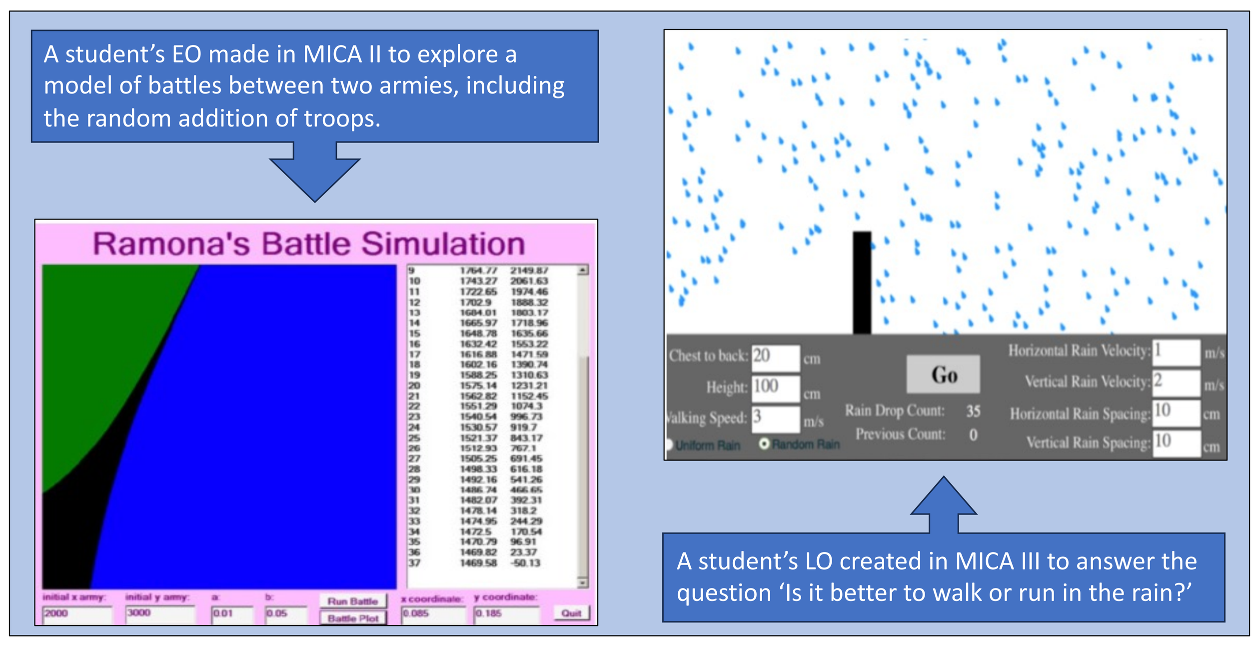
Introduction

"There has been a growing interest in studying and implementing innovative approaches in undergraduate mathematics, such as inquiry-based mathematics education (Laursen & Rasmussen, 2019), in which students are invited to engage in the practices of professional mathematicians. There is also a recent push to integrate computer programming – or more broadly, computational thinking – in different subject areas and at all levels of education (Wing, 2014); though the potential of integrating programming in mathematics learning has been known for a long time (Papert, 1980), including at the undergraduate level (e.g., Wilensky, 1995). In particular, programming can support a certain inquiry-based approach, where students engage in computational practices used by some professional mathematicians (Weintrop et al., 2016).
Some undergraduate mathematics curricula have integrated programming in this sense. For example, at Carroll College in the United States, mathematics majors use programming as a problem-solving tool throughout their mandatory coursework (calculus, linear algebra, modelling, abstract algebra, etc.) and may eventually apply their programming skills in senior projects or theses (Cline et al., 2020). Another example, in the Canadian context, is [the MICA courses at Brock University].
In their recent "Call for Research that Explores Relationships between Computing and Mathematical Thinking and Activity," to the international RUME community, Lockwood and Mørken (2021) argue that "serious consideration of machine-based computing [including programming] is largely absent from much of our research in undergraduate mathematics education" (p. 2). They suggest that much more needs to be investigated. The authors also point out that the various approaches to integrating computing in university mathematics classrooms should provide opportunities for research." (Broley et al., 2022)

MICA Course Context

The research takes place in the context of a sequence of three courses called Mathematics Integrated with Computers and Applications (MICA), which have been implemented at Brock University since 2001 (MICA I, MICA II, and MICA III/III*- III for math and science majors, III* for preservice teachers).
These courses engage students in a sequence of 14 projects, each course with 3-4 predetermined EO's (exploratory objects) and a final project (LO, learning object), in which they design, program, and use interactive computer environments to investigate mathematics concepts, conjectures, theorems, or real-world situations (Buteau et al., 2015). In MICA I,II,III, the final project topic is student-selected and in MICA III* the final project is a student designed teaching resource of a programming-based math activity.



Research by the Team

In an extended 5-year S.S.H.R.C.-funded (2017-22) research study, the team, led by Prof. C. Buteau (Brock Department of Mathematics and Statistics), has addressed this gap, using the opportunity provided by the 'natural' MICA environment (i.e., data was collected in MICA courses, without teaching interventions from the researchers). In particular, the team examines the teaching and learning of using programming for engaging in pure or applied mathematical inquiry (ctuniversitymath.ca). It aims to better understand how university students learn to use programming as a meaningful tool for mathematics ('as mathematicians do'), and how instructors and universities can support that learning (Buteau et al., 2018).

Using the Instrumental Approach (Rabardel, 1995/2001) as the main theoretical framework, the team has described how university students develop, through a process called 'instrumental genesis', so-called 'schemes' (i.e., actions for certain goals, and beliefs and understanding that drive those actions; Vergnaud, 2009) to effectively use programming (artefact) to conduct mathematical investigations; for example, the scheme of *articulating a mathematical process in a programming language* (e.g., Gueudet et al., 2022). The team study has included e.g. the identification of the programming-based math activity aspects students find most challenging (such as the scheme aforementioned) and why, and how they handle these challenges (Broley et al., 2022). In addition, the team examined actions and decision making by instructors that aim at steering their students' instrumental geneses of using programming for mathematical investigations (Buteau et al., 2023), i.e., what is called the 'instrumental orchestration' (Trouche, 2004). For example, the team identified orchestration features that students found effective in supporting their instrumental genesis, such as different types of individual interventions in labs and the need for a non-judgmental learning environment (Broley et al., 2022).

Our Research Question

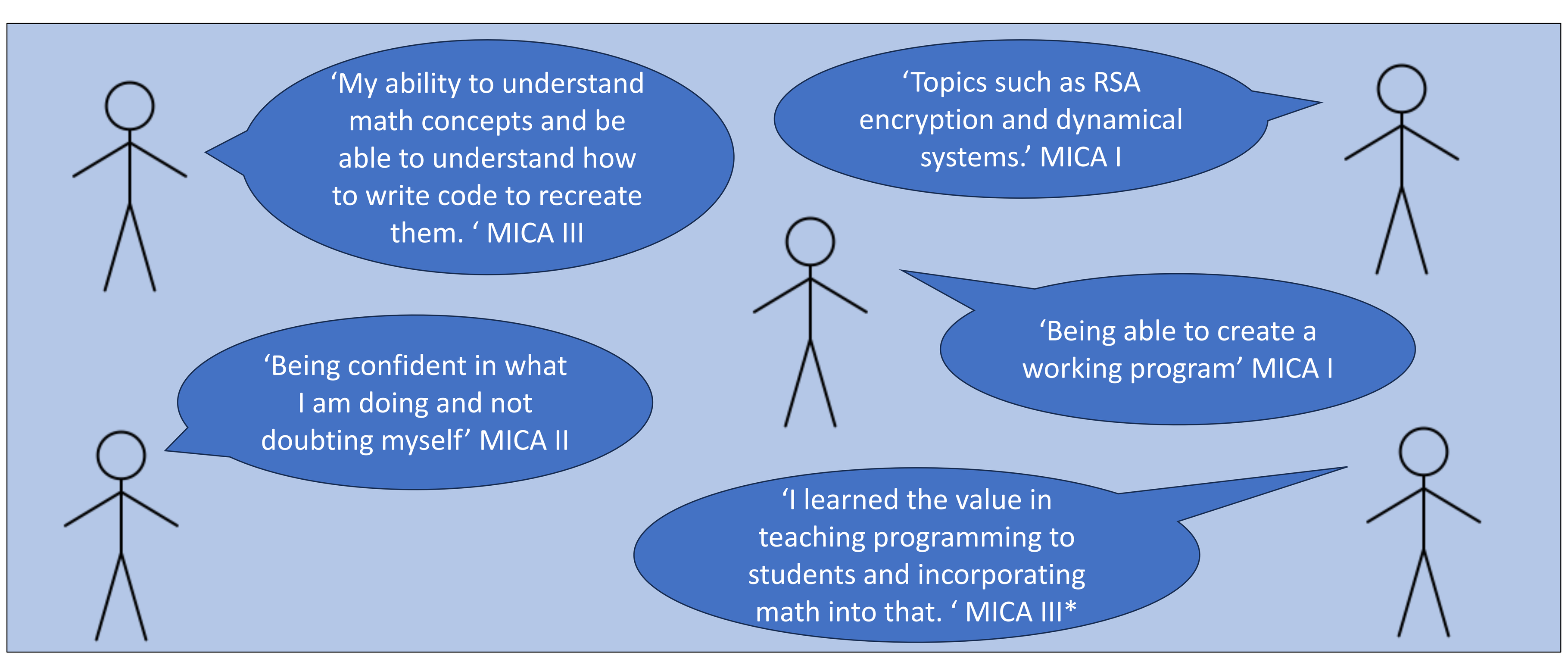
This study aims to expand the research on student learning with a focus on their learning experience perception. Namely:
What do undergraduate math students experience as satisfying learning achievements or moments from engaging in programming-based mathematical inquiry projects?

Methodology

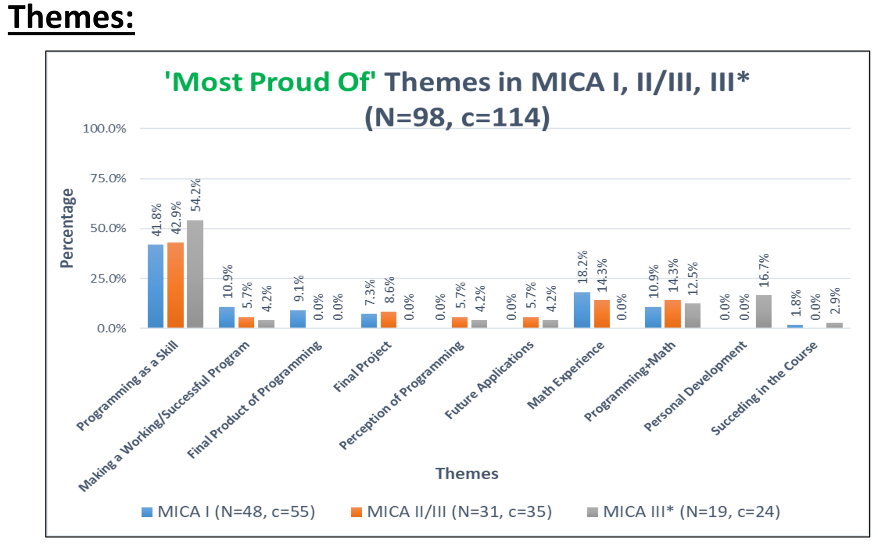
Participants: 98 volunteer students (MICA I = 48, MICA II = 28, MICA III*= 19, MICA III = 3)
Data: Students' responses to a post-course online questionnaire, specifically short responses to the questions: **'The thing(s) that I learned in [MICA I,II,III,III*] courses that I'm most proud of is (are)'** and **'because'.**
Qualitative Analysis: We initially thematically coded the responses individually, then collaborated to discuss and come to agreement on final codes for each response (Creswell, 2014). We then grouped the codes into themes (separately for each question), which we then further grouped into overall categories based on similar experiences and created graphical representations to analyze this data. **MICA II and MICA III were grouped together during analysis due to a small sample size in MICA III*

Results

The thing(s) that I learned in the [MICA I, II, III, III*] courses that I'm most proud of is (are):

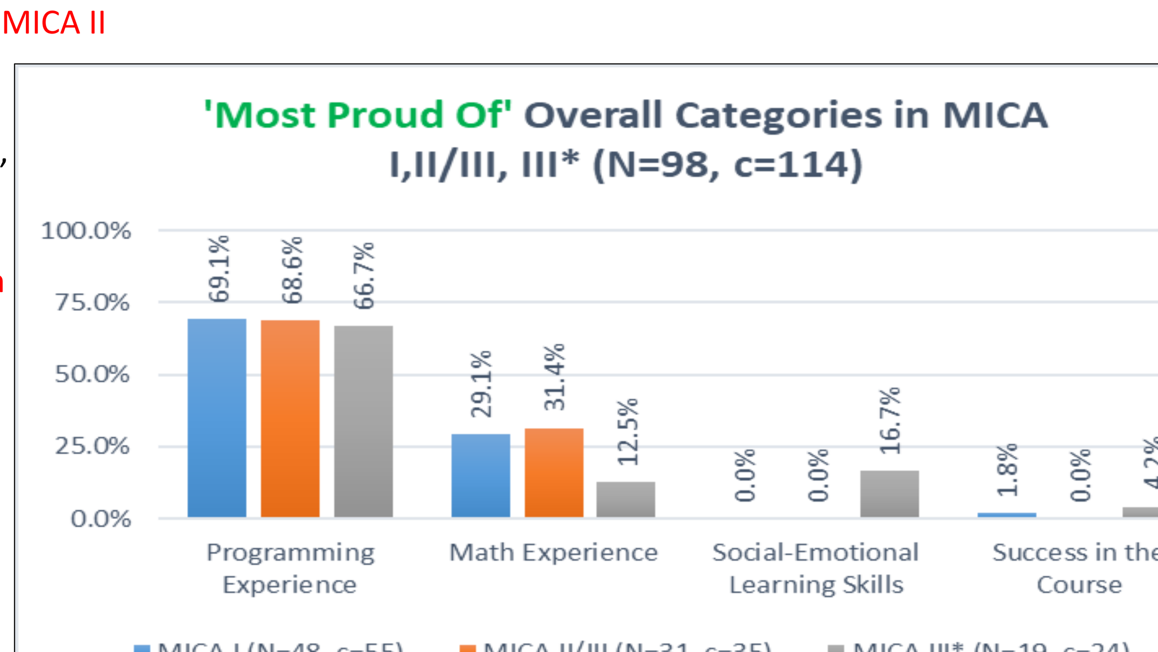


Themes:



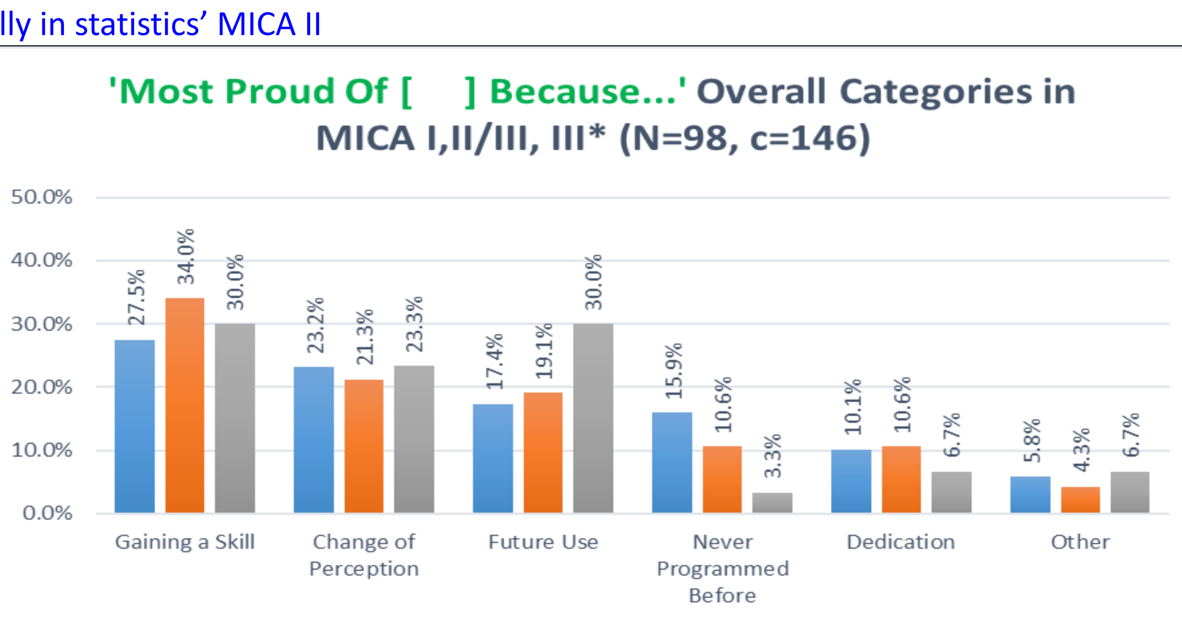
1. **Programming as a Skill -** I learned or improved to write and understand code in one/multiple coding languages independently
2. **Making a Working/Successful Program -** When I made a program that ran and successfully produced the required output
3. **Final Product of Programming -** My final code/program produced
4. **Final Project -** My final code/program produced of my final project
5. **Perception of Programming -** How my perception of programming changed after taking the course(s)
6. **Future Applications -** I learned a skill(programming) which can be applied outside of the MICA courses
7. **Programming+Math -** I used a skill (programming) to solve math problems/ I now understand the value of using programming for math
8. **Math Experience -** I learned and understood the math concepts
9. **Personal Development -** I developed skills and traits that furthered my personal capabilities and potential (agency, resilience, perseverance)
10. **Succeeding in the Course -** I succeeded in the course by completing the assignments to a respectable degree or receiving good marks

Categories (with selected excerpts):
Programming Experience (Themes 1-6): relates to the students' act of programming and their personal experiences specifically related to programming during the course and/or in the future.
'Learning how to code at all.' MICA I
'Getting a general feel for coding and building the foundations you need to code in the workplace' MICA III
Math Experience (Themes 7-8): relates to students' learning and perception of certain math concepts and/or how to use programming to articulate these math processes.
'Topics such as RSA encryption and dynamical systems.' MICA I
'Applying programming to math concepts' MICA II
SEL Experience (Theme 9): relates to students' awareness of how the course(s) have developed their personal capabilities, potential, and related skills such as perseverance, agency, and resilience.
'I learned that with minimal guidance I can self-direct my learning myself, promoting agency.' MICA III*
Success in the Course (Theme 10): relates to the perception of their own success in the courses, including receiving good grades and completing assignments.
'Achieving and completing many of the projects assigned to a respectable degree.' MICA I



Because...

Categories (with selected excerpts):
Gaining a Skill: being proud because they learned a new skill.
'I can now look at a code and somewhat understand what the code is saying' MICA I
'It took a long time to get where I am with confidence level and the ability to work incrementally' MICA III*
Change of Perception: being proud because they had a positive change in perception.
'At first it was confusing but after understanding the concept it was quite fun.' MICA I
Future Use: being proud because they can apply what they have learned outside of the MICA courses.
'It is going to be effective in the future if I ever need to program in the classroom' MICA III*
'It is very useful for all types of jobs, especially in statistics' MICA II
Never Programmed Before: being proud because they have never programmed before.
'It was my first time and I'd never done anything like that' MICA I
Dedication: being proud because of their dedication to succeed.
'I never thought I could pull off what I pulled off. I surprised myself with the effort and time I put into and that I did it with minimal help.' MICA I
Other: summarizes all the remaining responses that were not represented in other categories.



Preliminary Discussion

***Gaining a Skill* is the most common reason explaining their pride in all courses (other then MICA III* where it is tied with *Future Use*)** – *Gaining a Skill* is the most tangible reason to be proud reported, so it is the category students most acknowledge
***Change of Perception* is very prominent across all MICA courses** – This may suggest the MICA courses can promote a change in students' mindsets about math, math learning, and/or learning, and students are aware of the change and are proud of it
Future Use* is the most prominent reason of pride in MICA III - MICA III* also involves a focus on applications in a school math classroom where MICA I, II, III focus on learning in the moment and have implicit implications about future use
***Never Programmed Before* is less prominent as the course gets higher -** Students are not programming for the first time in later courses as they had to have taken MICA I and MICA II and the pride of programming for the first time wears off the more they do it

***Programming Experience* is the most prominent and consistent category** – Students had a different experience in these courses, no other math courses teach/integrate programming so it may be why it stands out more as an experience. This category is also representative of many different themes related to programming so there are many more ways pride can be represented within this category compared to the others.
***Math Experience* is less prevalent for MICA III* students** – There are more future teachers in MICA III* vs the other courses where more students are majoring in Math/Stats, this means they could be perceiving MICA III* as an educational course for teaching math in the future rather then educational for the math concepts themselves
***SEL Skills* is only prevalent for MICA III* students** - This could be due to the reflections/readings throughout the MICA III* course and/or more of a teacher mindset, i.e., for them, process/experience is also important, not only the 'outcome'
***Success in the Course* has the smallest frequency** – This is the only category that is based on extrinsic motivation, whereas the other categories are intrinsic, this suggests that student's pride most often comes from their own motivations and capabilities rather than from external gratifications

Limitations

This study is limited by the participation in the post-questionnaire survey being voluntary, so the responses and the analysis do not reflect the entirety of the students in the MICA courses. This also affected the number of participants who responded per course, causing an uneven sample size between the MICA courses.

What's Next?

As this study is part of a larger research project, the next step for the research team will be to use the results to expand their conceptualization of students' learning experiences i.e., to develop a more holistic view. In other words, more time needs to be applied to connecting this study and its findings to the theoretical framework of the larger research project. By doing so, the research team will be able to understand and benefit from knowing 'what' the students are most proud of and 'because' by using existing theory to support the results in order to answer the research question proposed here. In addition, the data analysis and observations obtained from this study are preliminary and require further time and consideration to elaborate on their interpretation in the context of the literature.

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