Evaluating the impact of student-centred computational activities on sensemaking and computational thinking in Financial Mathematics

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In this paper, we evaluate the computational lab component of a mandatory undergraduate Computational Finance course. We were interested to determine if and how the computational design of each lab contributed to students' sensemaking around the concept of computational thinking. We also examined the interplay between financial mathematics and computational thinking for students. Using thematic analysis, we analysed six students' responses to ten weekly surveys, one conducted at the end of each lab for ten weeks in 2020/2021. A set of 11 categories describing the main themes from the students' responses were generated with 'Improved Computational Thinking' being the most significant for student learning. Results also show that the learning outcomes of each lab were clear to almost all six students for all ten labs.

Keywords: Sensemaking, financial mathematics, computational thinking, inclusive computational practices.

Introduction

In recent years, scientific computing and computational thinking have become key drivers in many STEM areas. For future researchers, computing competences must be brought to the forefront of undergraduate education in universities, in particular for mathematical subjects (Lockwood et al., 2019). If university courses were designed to include computational thinking, students would almost certainly graduate with at least a foundational understanding of this important skill (Caballero & Hjorth-Jensen, 2018). In this setting, Financial Mathematics (FM) is a new and highly interdisciplinary mathematical subject, where computational thinking skills are fundamental for covering high-level quantitative finance roles as well as perform academic research with significant real-world impact.

At the same time, there are growing concerns that university students of computationally rich courses are not fully aware of the mathematical ramifications of their code design, its output and its real world meaning (Sand et al., 2022). As computer technology advances at an unrelenting pace, students are being exposed to more black box methods which have the potential to mask the principles of the underlying mathematics. This proposed research study aims to contribute to the FM curriculum, showing how tailored student-led computational practices designed for a Computational Finance module delivered at University College Dublin (UCD) provided opportunities to foster sensemaking in FM and improve computational thinking. We analysed students' responses to weekly surveys to address the following research questions:

RQ 1 To what extent do inclusive computational practices engage students in sensemaking in Financial Mathematics?

RQ 2 To what extent do inclusive computational practices engage students in developing computational thinking?

Despite the incredible growth of Financial Mathematics programs, the Computational Finance curriculum is under-researched; our study aims to contribute to this. A similar study is found in Barana et al. (2023), where the authors investigate the effectiveness of inclusive computational practices in providing opportunities for the *co-creation of knowledge* in Computational Finance within a Computer Supported Collaborative Learning environment.

Theoretical Framework

Designing engaging enquiry-based learning environments in science modules is fundamental to developing computational thinking. *Computational thinking* is a common phrase to which numerous definitions have been attached. Aho (2012, p.832) defines computational thinking as "the thought processes involved in formulating problems so their solutions can be represented as computational steps and algorithms", while Wing (2014) states that computational thinking is "the thought processes involved in formulating a problem and expressing its solution(s) in such a way that a computer - human or machine - can effectively carry out". This is the definition we adopt in this work. More precisely, we refer to the definition given by Lockwood et al. (2019, p.3), which aligns Wing's to a mathematical context, as "the practice of using tools to perform mathematical calculations or to develop or implement algorithms in order to accomplish a mathematical goal".

There are numerous advantages to incorporating computational thinking into undergraduate courses. As mentioned in Caballero and Hjorth-Jensen (2018), educators could enhance students' learning and understanding, leading to deeper insights being gained from the taught material. Educators have the potential to expose their students to a myriad of real-world examples and more complex problems at an earlier stage. These practices can undoubtedly lead to students having a more well-rounded and applicable education upon graduation. With this aim, Caballero and Hjorth-Jensen (2018) have developed an "inclusive computational" framework which we adopt in this study. *Inclusive computational practice* is a concept encompassing several computing-related activities, such as: (1) students working alone or in groups with algorithms to understand the underpinning ideas of a mathematical or financial model; (2) having students adapt lines of code to suit a similar, but different, problem; (3) having students inspect and comment critically on computational inputs and outputs. Inclusive computational practices have been used extensively to design physics undergraduates' modules at Michigan State University and Georgia Tech, USA (e.g., Caballero et al., 2012; Irving et al., 2017; Caballero & Hjorth-Jensen, 2018). They have included computation and computational thinking as a central element, and not simply as a tool in the design process. Since 2020, Author 2 has redesigned many computational practices including (1)-(3) above, for a Computational Finance module at UCD, with the aim to provide students with opportunities to foster computational thinking and sensemaking in FM. A comprehensive description of the module design can be found in Perrotta (2021), while a focus on the design of inclusive computational practices for FM is presented in Perrotta and Dolphin (2021).

Many researchers agree on an intuitive definition of *sensemaking*; however, the related literature is fragmented. The definition of sensemaking given by Odden and Russ (2018) has been adopted in Perrotta (2021) and in Perrotta and Dolphin (2021) as well as in this study. Odden and Russ describe sensemaking as “a dynamic process of building or revising an explanation in order to *figure something out* - to ascertain the mechanism underlying a phenomenon in order to resolve a gap or inconsistency in one’s understanding” (2018, p.13). According to Odden and Russ, the sensemaking process begins when “something is puzzling or unexpected” or when “there is some gap in existing knowledge, individual facts or ideas conflict with one another, or some combination of these” (2018, p.6).

The Research Methodology: a pilot study

In this study, we attempt to shed light on how undergraduate students make sense of connections between computing and financial mathematics via their work in groups in the student-led labs activities described in Perrotta and Dolphin (2021). We analysed responses to three questions per student over a ten-week period during the Spring of 2020/2021 using a Google Survey. We performed a qualitative analysis, using the approach to thematic analysis developed by Thomas (2006). Thomas (2006) outlines a set of procedures to carry out qualitative analysis, aimed at new researchers or researchers from non-social science areas so that they need not be fluent in the underlying philosophical or technical terms often embedded in thematic analysis, and qualitative analysis more generally. Thomas developed an inductive approach which involves “detailed readings of the raw data in order to derive concepts, themes, or a model through interpretations made from the raw data by an evaluator or researcher” (2006, p.238), with the aim of an inductive approach being to “allow research findings to emerge from the frequent, dominant or significant themes inherent in the raw data, without the restraints imposed by structured methodologies” (2006, p.238). The output of this inductive approach is then “the development of categories into a model or framework that summarises the raw data and conveys key themes and processes” (2006, p.240). Given the non-social science context of our research study and the fact that we analyse students’ short responses instead of recorded conversations, we decided to adopt Thomas’ approach.

This research study was conducted in 2020/2021 in the Computational Finance module ACM30070, a core module for Stage 3 of the BSc in FM, at UCD. The module is also optional for Stage 3 of the BSc in Applied and Computational Mathematics (ACM). The class comprised 50 students, 35 FM and 15 ACM students, 40 were male and 10 females. The module was created in 2017 and then significantly redesigned by Author 2 in 2020 to include several *inclusive computational practices* in the module’s labs. These inclusive computational *practices* were designed to enhance students’ computational learning and sensemaking in FM within a collaborative computer supported learning environment (Perrotta, 2021; Perrotta & Dolphin, 2021). Weekly lab activities were student-led and involved the participation of the lecturer, a tutor and a teaching assistant as facilitators. The same lab structure was proposed each week with each applied to different computational practices. Each lab lasted two hours. During the first hour, students worked in groups on computational modelling, pseudo-coding, data analysis and other related computer-based activities as (1)-(3) above. In the second hour, each group chose a representative to present the group's results to the whole class. The tutor guided groups in presenting their results and encouraged them to agree on a shared conclusion. There were seven groups participating in the activity (six with seven students and one with eight), which remained constant for the term. Students were grouped according to: their GPA, (i.e. similar GPA, on average), their pathway (5 FM and 2 ACM), and gender balance (at least two females per group, otherwise no females). The impact of co-construction of knowledge during these lab activities is investigated in Barana et at. (2023). After each lab, students were invited to complete a Google Form survey to critically reflect on class activities. The weekly survey ran for ten weeks in Spring 2021; so, each student completed ten surveys. The survey contained qualitative and quantitative questions and the responses constitute the dataset for this study. The definition of sensemaking was included in the survey preamble so students were familiar with it. Ethical approval for this research study was granted in Spring 2020 (LS-20-05-Perrotta). In this paper, we analyse open-ended responses to the following questions, extracted from the Google Survey:

> Were the expected learning outcomes of the lab clear? Please explain.
>
> Was there any content area or computer code that was unclear prior to the lab that is now clear? Please explain.
>
> Can you describe in detail how the use of computation facilitated your sensemaking?

For this pilot study, we selected six out of 50 students, each of whom worked in a different group. This selection was made to represent three different proficiency levels: two students came from two high-performing groups, two from two medium groups and two from two low-performing groups. We analysed the six students' responses to the ten weekly surveys for Q1, Q2 and Q3 using Thomas' approach to thematic analysis. These six specific students were selected as their answers were well elaborated giving ample material for category generation in the qualitative analysis. It is noteworthy that lab attendance was not compulsory, so sometimes students missed a lab and consequently did not complete the survey. This justifies the frequencies shown in Table 1 below (see Labs 4, 5, 6, 10). Also, some questions' answers were left empty even when a student attended a lab. In conclusion, we analysed a total of 165 responses from the pilot study.

Guided by Authors 2 and 3, Author 1 coded the subset of six students' responses for all ten weeks to generate the initial set of 17 categories. Author 2 then independently repeated this process, generating a set of 21 categories. Author 1 and Author 2 merged their sets of categories, refined them, and resolved any discrepancies. They defined a set of 15 categories. At this stage, Author 3 independently coded survey responses for six students from four labs (labs 1, 2, 3, and 7). These labs were chosen because each of the 15 codes appeared at least once among them, but also because most codes were heavily highlighted. He started from the set of 15 categories applied to each response and further refined them, merging some categories into a unique one. At this time, authors also decided to perform qualitative analysis only on the responses to Q2 and Q3, while for Q1 instead we used a binary variable, with 1 indicating clear learning outcomes (LOs), and 0 indicating otherwise. The frequencies of the binary variable used in Q1 are shown in Table 1.

At the end of this process, the three authors agreed on the final list of 11 categories described below:

1. **Choosing Effective Computational Tools (CECT):** Student indicates that they have a better handle on choosing the most efficient computational tools with which to solve a FM problem.
2. **Coding as a Means to Apply a Method (CMAM):** Student discusses the use of coding to apply/implement a FM method about which they have learned.
3. **Coding for Real World Applications (CRWA):** Student acknowledges the importance of coding to solve real world applications.
4. **Coding to Sensemaking (C2S):** Student demonstrates sensemaking as a result of a coding activity.
5. **Debugging/Troubleshooting for Learning (DTL)**: Student indicates that they learned something through the debugging/troubleshooting stages of the lab.
6. **Financial Mathematics to Improve Computational Thinking (FM2CT)**: Student indicates that their FM knowledge helped to improve their CT skills.
7. **Group Discussion Aided Understanding (GDAU)**: Student acknowledges that the group discussions aided their understanding.
8. **Improved Computational Thinking (ICT):** Student improved their CT skills utilising the coding skills element of the lab.
9. **Unclear about Modelling (UM)**: Student indicates that they are unclear about the FM modelling concepts present in the lab.
10. **Understand the Theory (UT)**: Student shows that they have gained a better understanding of the FM theory through this lab activity.
11. **Use of Prior Learning to Build New Knowledge (UPL2BNK):** Student acknowledges their prior learning as a foundation on which new knowledge has been built.

Results

Table 1 shows the frequencies of the binary variable used in Q1. LOs were clear for at least 80% of the six students in all the labs, and for all of them in six out of ten labs. Moreover, LOs were clear to 100% of the students in the last four labs, when students would have been familiar with the proposed activities.

Table 1

Frequencies of 0/1 in Question 1

	Lab 1	Lab 2	Lab 3	Lab 4	Lab 5	Lab 6	Lab 7	Lab 8	Lab 9	Lab 10
Frequency of students who found the LOs clear	5/6	6/6	5/6	4/5	4/4	4/5	6/6	6/6	6/6	5/5

Table 2 below shows the observed frequencies of the 11 categories that we identified performing a qualitative analysis of Q2 and Q3 answers.

Table 2

Frequencies of Categories in Questions 2 and 3

Category	Count	%
ICT	46	27
FM2CT	21	12
UT	19	11
UM	15	9
GDAU	14	8
CECT	13	7
UPL2BNK	13	7
C2S	11	6
CMAM	8	5
DTL	7	4
C2RWA	6	4

These results show the positive effect of the lab design on the interplay of FM and CT. Indeed, each notion supports the other in terms of students' sensemaking and without the computing element of the module this would be highly unlikely to occur, based on Author 2's experience of teaching FM without such accompanying computational labs. The category "Improved Computational Thinking" occurred 46 times, indicating that students noticed their computational thinking skills being improved as a direct result of the implemented inclusive computational practices. The next most popular categories were "Financial Mathematics to Improve Computational Thinking" and "Understand the Theory", which occurred 21 and 19 times, respectively. An example of a segment in which both ICT and UT occurred is shown below:

> We used the aaBin function to price put and call options […]. The most educational part for me was to not[e] the vast difference in options prices when the time to maturity and the spot price is 10 euro above the strike price. […] This prompted much speculation and debate in our group as to the reason why […]. We also used Fincad to evaluate the put-call parity with a time to maturity of two years now […]. This computational aspect allowed me […] to solidify the truth of the put call parity.

Here, the thought process involved in formulating the problem, testing potential approaches to solutions, scaffolding the process in computational steps, and finally coming to a conclusion is very well described. Also, the student makes explicit the fact that this lab activity contributed to solidifying their FM knowledge. Conversely, an example of an extract in which the category FM2CT occurred follows:

> Before it was mostly just copying text and analysing the lines, which is of course vital, but this lab allowed me to try implement this in designing my own code

> from scratch. I found that if there was […] lines of code that I only half understood before I really had to figure out what they meant and why they worked for my code.

From this extract, we can see that the FM model behind the practice strongly contributed to fostering the student's computational thinking.

The category "Coding to Sensemaking" occurred 11 times. In the following extract, the student shows that he has completed the sensemaking process described by Odden and Russ (2019):

> I think that the labs that require us to design some code prior to the lab help me to understand the computational part of the course best. It's one thing to read the other code and implement it but the opportunity to write your own forces you to understand the deeper intricacies in the code and you become more aware of the parts that you do and do not understand, which you can then fix.

We highlight that detecting sensemaking from an asynchronous response to a Google Form is a hard task, since it heavily relies on the ability of each student to remember what happened in class and to then put the entire learning process into words. We expect a higher number of occurrences of the C2S category once the entire dataset of responses has been analysed.

Summary and future research

We performed a pilot study to investigate the effectiveness of tailored student-led computational lab activities in sensemaking in FM (RQ1) and in developing computing thinking (RQ2). We selected six students out of 50 undergraduate students attending the UCD Computational Finance module in 2020/2021 and analysed their responses to a weekly survey over 10 weeks. To frame our study, we referred to the Lockwood et al. (2019) definition of computational thinking in mathematics and to the Caballero et al. (2018) inclusive computational framework. We performed a thematic analysis (Thomas, 2006) to generate 11 categories from the students' responses. Results are shown in Tables 1 and 2 and are in line with the available literature in which inclusive computation is used to foster sensemaking in physics undergraduates. The category "Improved Computational Thinking" occurred 46 times, while "Financial Mathematics to Improve Computational Thinking" and "Understand the Theory" occurred 21 and 19 times, respectively. This result allows us to conclude that the proposed activities successfully contribute to the enrichment and knowledge of FM and students' computational thinking. The technology and computation used in this module played a key role, since they mediated and fostered the learning process. We are currently planning to extend the analysis to the entire dataset during which we will further refine the categories, seek links between them and define summarised themes. We will also investigate how computation combined with a collaborative learning environment fosters the learning process. To this aim, we will correlate our results with those of Barana et al. (2023).

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