What challenges do students face in introductory STEM courses, and how can instructors help?

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ABSTRACT: This study focuses on the pivotal role of sense of belonging within introductory STEM courses, particularly its impact on student performance and their intention to persist in the discipline. It is well-documented that doubts concerning sense of belonging within the classroom disproportionately affect students from marginalized groups, ultimately leading to underperformance and potentially explaining the attrition rates of certain demographics, such as women, in STEM fields (Cohen et al., 2008). To complement ongoing research on belonging (Hammarlund et al., 2022), and recognizing the connection between belonging and how students perceive and manage academic challenges, our study aimed to investigate self-reported challenges and coping strategies among introductory STEM students at the University of Bergen. More specifically, we conducted a survey among students enrolled in an introductory computer science course (n=176), which is mandatory for all undergraduates at the Faculty of Mathematics and Natural Sciences. To explore their anticipated difficulties, we posed a single open-ended question: "*Today, we'd like each of you to reflect on some of the concerns you may have about taking this course. What do you think will be difficult or challenging for you*?"

Student responses were analysed using an inductive coding approach, whereby we categorized their comments into specific groups and further organized these categories into broader themes. For instance, a student expressing concerns about their understanding of the material was categorized under "comprehension," while another student's statement regarding fear of falling behind the class was classified as "afraid of falling behind." Our study's findings provide valuable insights and, to some extent, offer encouragement, as many of the concerns raised by students can be addressed through deliberate instructional decisions. To conclude, we present an illustrative example of how instructor behaviours can effectively alleviate common apprehensions among students enrolled in introductory science courses.

1 INTRODUCTION

As instructors in higher education, our aim is to cultivate an inclusive learning environment that promotes equal opportunities for all students, leading to high retention rates, exemplary performance, and overall course satisfaction. Introductory courses, in particular, bear the responsibility of introducing students to a specific discipline and assisting them in making informed decisions about their future academic paths. Previous studies in various fields have established significant associations between student affect (such as self-efficacy, sense of belonging, and test anxiety) and outcomes (including academic performance and student retention). Given the malleable nature of student affect, which can be influenced by instructional choices, there is a compelling need for further investigation. In this study, we specifically concentrate on exploring the sense of belonging among students enrolled in introductory computer science, recognizing its potential impact on students' overall educational experiences.

The impact of student sense of belonging on various aspects of education, including attrition (O'Keeffe, 2013), performance (Inzlicht, 2006), engagement (Thomas, 2012), and self-efficacy (Freeman et al., 2007), has been extensively studied in educational research. In the field of computer science, the connection between a student's sense of belonging and their perception of their own abilities has been highlighted, potentially outweighing actual performance (Veilleux et al., 2013). This finding aligns with

similar observations in other disciplines such as mathematics (Good et al., 2012), engineering (Walton et al., 2015), and science more broadly (Rainey et al., 2018). Belonging is inherently intertwined with how students interpret and navigate challenges, prompting recent studies to focus on student perceptions of challenges within their courses. As part of an ongoing replication study of Hammarlund et al. 2022 conducted in a Norwegian context, students enrolled in a first-semester computer science course were invited to articulate their anticipated challenges for the course. The underlying rationale was that by gaining insights into students' perceptions of challenges, instructors can make informed instructional decisions aimed at alleviating some of these concerns. Consequently, this approach can contribute to enhancing students' sense of belonging, which in turn positively influences their performance, disciplinary identity, and retention within the field.

2 STUDY CONTEXT

INF100 is an introductory programming course that covers the fundamentals of Python programming[1]. This course is compulsory for all students enrolled in the Faculty of Mathematics and Natural Sciences, with a total enrolment of 680 students during the Fall 2022 semester. The course adopts an interactive approach, prioritizing groupwork sessions focused on programming exercises, rather than relying heavily on traditional lectures. Each week consists of a two-hour lecture and two group sessions, where students receive guidance and support from group leaders[2] to successfully complete the assigned tasks. To be eligible for the final exam and complete the course, students are required to pass multiple weekly assignments throughout the entire semester. The survey we conducted for this study took place two days after the deadline for the first weekly assignment. At this time, the policy in place required students to successfully complete a minimum of 7 out of the 11 assignments in order to be eligible for the final exam. This policy set a specific benchmark for students to meet in terms of their assignment performance throughout the course. It is important to note that this policy may have influenced student motivation and engagement, as it established clear expectations regarding their progress and the requirements for advancing to the final examination.

Table 1. Answers to the prompt "How would you rate your programming ability in Python?" (n=436).

	n	%
Have not programmed before	221	50.69%
(1) Know a little	122	27.98%
(2)	53	12.16%
(3)	33	7.57%
(4)	7	1.61%
(5) Skilled	0	0.00%
Mean score	**1.65 / 5.0**	

INF100 serves as an initial introduction to the realm of computer science for many students. While the majority of students enrolled in this course are embarking on their first semester of higher education, it is worth noting that some students may have encountered programming in high school or earlier educational settings. To assess the prior programming knowledge of the students, a survey was administered during the first week of the course. The results revealed that 50.69% of the students had never engaged in any programming activities previously. The remaining 49.31% who had some programming experience, were asked to rate their proficiency in Python using a 5-point Likert scale (*Table 1*). Even among those who had prior experience, their knowledge and expertise were relatively limited, as indicated by a mean Likert score of 1.65 out of 5. Specifically, when it came to programming in Python, only 36.47% of students reported having some familiarity with the language. This scarcity of prior knowledge was also observed by the course instructor during teaching activities at the beginning of the course.

[1] https://www.python.org/

[2] A group leader is a student studying a bachelor or masters, who has a paid part time position in a course which they finished one or more years earlier.

3 METHODOLOGY

The students were given a sheet of paper with the prompt *"Today, we'd like each of you to reflect on some of the concerns you may have about taking this course. What do you think will be difficult or challenging for you?"*. This prompt mirrors that used in Hammarlund et al. 2022, and Binning et al. 2020, and was part of a larger study on student belonging in introductory-STEM courses. Students had 10 minutes to write before the sheets were collected. No phone or computer was allowed at the table during this time.

The student responses were transcribed and subjected to an inductive coding approach (Thomas 2003) placing the concerns and challenges into a set of categories. To ensure reliability and consistency, a random sample of 30 responses was selected and independently categorized by two authors. After completion, the categorizations were compared, and a consensus was reached on a final set of categories. Subsequently, the remaining responses were assigned to these agreed-upon categories. It is important to note that a single response could be allocated to multiple categories if applicable. All materials and responses used in the study were translated from Norwegian for analysis and interpretation.

4 RESULTS

The coded responses can be found in *Table 2.*

Table 2. Coded responses from challenges prompt (n=176).

Challenges	**n**	**%**
Mandatory assignments	70	39.77%
Comprehension	60	34.09%
Programming language	49	27.84%
Little/no experience with programming	43	24.43%
Difficulty in self-study	38	21.59%
Deviation between theory and practice (lecture and assignments)	36	20.45%
Moving forward too quickly	32	18.18%
The curriculum is too hard	27	15.34%
Afraid of falling behind (the class)	24	13.64%
Steep learning curve	23	13.07%
The exam / failing	23	13.07%
Hard to find/use resources	20	11.36%
Advice/suggestions for teaching	17	9.66%
General concern for the subject	14	7.95%
The lecturers' expectations	14	7.95%
Workload does not match the allotted time	13	7.39%
The math/logic part of programming	12	6.81%
Hard to get help	10	5.68%
Study technique	7	3.98%
No worries	6	3.41%
Issues with group sessions/leaders	6	3.41%

In our discussion, we specifically concentrate on selected challenges that were reported by 10% or more of the students, as these represent the primary concerns expressed by the student population. It is noteworthy that the total number of students contributing to each category amounts to 544, as some students provided responses that encompassed multiple codes, which were subsequently divided and assigned to relevant categories accordingly.

The most common concern expressed by the participating students was *Mandatory assignments* (70 out of 176 student responses, or 39.77%). For example, two individuals wrote:

> *"Far too many difficult questions on the weekly assignments, which you cannot solve alone either."*

> *"Difficult to understand what the assignment is completely asking for, what is challenging is that there are submissions every week which makes it difficult to keep up."*

The first assignment[3] (which was due two days before these submissions) required the student to utilize the basics of the following programming concepts:

- Printing
- Reading input
- String manipulation
- Conditionals
- Standard functions
- Custom functions

Given that there were no prerequisites for this course, it was anticipated that students, even those without any prior programming experience, would be able to tackle these tasks within one week of study. However, this particular expectation was recognized as a challenging endeavour for new students. The course instructors devised a work plan that involved initially imposing a demanding workload and subsequently reducing the intensity as the semester progressed. However, it is important to note that this plan was not explicitly communicated to the students. The instructors intended for this work scheme to serve as a means for students to realize the inherent difficulty of programming and comprehend the substantial effort and dedication required to master the subject. Consistent and sustained effort in programming was strongly recommended, and the initial assignment was designed with the intention of setting students on this path of commitment and growth.

Many of the other categories also relate to the difficulty of the course and the perceived performance of the students. Note that many of the comments below were assigned to multiple categories but are shared here as exemplars for single categories.

Comprehension: 34.09%
"I am worried about looking too much at the solution and not understanding fundamental elements. I am worried about failing the course."

Programming language: 27.84%
"I think the content will be difficult because I have never programmed. Most of it seems Greek. In addition, it takes very little for a program to crash, and it is difficult to discover what is wrong."

Little/no experience in programming: 24.43%
"I have no previous experience with programming. Worried about not being able to find a solution on my own. Worried about dropping out from the start."

Difficulty of self-study: 21.59%
"I am most concerned about the subject's content because that I have no prior knowledge, and already notice that I understand very little. I also don't quite know how to work and do tasks on my own when I don't understand the tasks."

[3] The first INF100 assignment can be found here: https://inf100h22.stromme.me/lab/1/

Deviation between theory and practice (lecture and assignments): 20.45%
"That the lectures do not deal with things in the submissions."

Moving forward too quickly: 18.18%
"The challenges are that we move forward very quickly. Difficult to understand without prior knowledge of the subject."

The curriculum is too hard: 15.34%
"My worries: that I'm not smart enough, the material is a lot, and we rush through it."

Afraid of falling behind (the class): 13.64%
"Worried about coding badly and not keeping up with the rest of the class."

Steep learning curve: 13.07%
"The amount of material one must go through in a short time. The learning curve is so steep for the time you have at your disposal. Low learning outcomes from the lectures."

The exam / failing: 13.07%
"My worries are that I won't be able to code well enough for the exam. I'm worried that the material will be too difficult and that I won't learn anything. The learning curve has been quite steep so far and I'm worried that it will get even steeper."

Hard to find/use resources: 11.36%
"I think it can be difficult to know where I can find help in the resources we have been given, that I don't know where to look. It is also a little difficult to get to grips with python as I have not used it before."

5 DISCUSSION & CONCLUSION

A significant number of challenges reported by the students revolve around the perceived difficulty of the course material, with many expressing that the course is excessively challenging. This observation raises the possibility that such perceptions may contribute to or intensify feelings of inadequacy among students. This supposition is supported by comments indicating personal shortcomings, such as a lack of preparation, self-doubt regarding intelligence, and a sense of struggling to keep up with their peers. It is important to acknowledge that some of these concerns may have been amplified by the timing of the survey, which occurred immediately after the completion of the first demanding assignment. However, it is worth noting that these themes align with student concerns documented in previous studies, suggesting that similar responses may emerge irrespective of the survey timing.

"My worries: that I'm not smart enough, there is a lot of material, and we rush through it."

The purpose behind the assignment structure, with its initial difficulty followed by a reduction in workload over time, was to encourage students to engage consistently with the subject matter. However, it is crucial to examine whether this approach truly benefited student learning. Did students indeed exert more effort and acquire a deeper understanding of the curriculum, or did unintended consequences arise as a result? It is plausible that, upon encountering the demanding assignment and struggling to navigate it independently, students may have experienced a sense of inadequacy. This feeling of inadequacy could have triggered thoughts such as:

"I am not cut out for this."

"I don't have the necessary skills or intelligence to succeed."

"I won't be able to keep up with my classmates."

"I should give up or consider a different path."

"I do not belong here."

Although the data collected in this study does not provide specific insights into the consequences of the assignment scheme, it highlights the importance of considering these questions when designing course material. Understanding the potential consequences of a particular assignment structure is crucial for creating an effective learning environment. By examining the impact on student learning, engagement, and well-being, educators can make informed decisions and adjustments to optimize the learning experience for students. It underscores the need for further research and investigation to gain a comprehensive understanding of the consequences associated with different assignment schemes and their implications for student outcomes.

Another of the prominent concerns expressed by the students was a fear of falling behind their peers in the class, with 13.64% of the responses being placed in this category. This apprehension may be attributed to the fact that 49.31% of the students had prior programming knowledge. When a significant portion of the class has previous programming experience, it can create a perception among the remaining 50.69% that they are at a disadvantage and that others possess more knowledge than they do. This perception may have been reinforced by the challenging nature of the initial assignment, potentially leading students to believe that they were expected to have programming expertise prior to starting the course. This is supported by 24.43% of the students reporting *Little/no programming experience* as a concern. Examining the specifics of the prior knowledge among the 49.31% of students, it becomes evident that only a few were proficient in programming, while the majority had limited knowledge in the subject. To address this possible feeling of inadequacy arising from the belief that others have more knowledge, one instructional choice could be to provide transparency regarding the results of the prior programming experience survey. By highlighting that most students have limited or no prior experience, it can help alleviate the sense of being left behind. Reinforcing the fact that the course has no prerequisites and that the assignments are designed without assuming prior knowledge can also be beneficial in reducing feelings of inadequacy among students. Clear communication about the expectations and the inclusive nature of the course can help create a supportive learning environment for all students.

There is evidence to suggest that teaching interventions can effectively address the concerns expressed by students. Previous studies conducted in the United States, such as Hammarlund et al. (2022) and Binning et al. (2020), have demonstrated the potential benefits of brief, early-term interventions. For instance, both studies highlight the positive outcomes of an exercise where students engage in discussions about their apprehensions regarding the course. These discussions involve sample statements (fabricated) from previous students who have taken the course. The purpose of this belonging intervention is to help students internalize the notion that challenges in the course are temporary, normal, and can be overcome. By equipping students with the necessary mental tools to proactively manage challenges, this intervention aims to promote resilience and a sense of empowerment. In future research, efforts will be made to contextualize and implement this intervention beyond the United States. This will allow for a broader understanding of its effectiveness and applicability in diverse educational settings. By expanding the scope of this intervention, it is possible to further enhance student experiences and foster a supportive learning environment internationally.

5.1 Future work

Our intention is to replicate the study in a subsequent iteration of the course with some enhancements. Firstly, we aim to gather personal information from the respondents in order to establish connections between their challenges and factors such as performance, gender, and background. This additional data will provide valuable insights into the potential influences on students' experiences. Moreover, we plan to track the evolution of these concerns throughout the semester by conducting multiple surveys, enabling us to distinguish between challenges that are common at the beginning of the semester and those that persist over time. This longitudinal approach will provide a comprehensive understanding of the changing nature of student worries. Lastly, we aim to replicate the intervention described in the study conducted by Hammarlund et al. (2022) to examine whether similar benefits can be observed within the specific context of a Scandinavian computer science setting. By replicating the intervention, we can assess its effectiveness and determine its applicability in our target environment.

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