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Exploring a meaningful learning intervention in a CS1 course

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Abstract. *Meaningful learning is when students actively integrate new knowledge into their mental structures with purpose and emotion. While previous CS1 literature has explored ideas of meaningful learning, no studies have examined the specific aspects that emerge from students' learning processes during meaningful learning-driven interventions. To address this gap, we conducted an exploratory case study. We asked* 32 *students to keep learning journals to document their experiences in a CS1 course designed with a meaningful learning framework. We analyzed the journals qualitatively and found that students adopted the protagonist role in their learning process thanks to a network of influences stemming from the elements introduced in our intervention.*

1. Introduction

To develop lasting programming knowledge, learners must critically evolve their cognitive representation of theoretical and practical programming concepts with new learnings. Doing so allows them to apply their programming knowledge to new and unforeseen problems. The meaningful learning theory provides a framework for achieving this aim, incorporating different elements to consolidate knowledge by linking learned content and context [Ausubel 2012].

Several studies have applied some meaningful learning ideas to CS1 education. For example, some have used problem-[Chang et al. 2020] or project-based [Souza and Bittencourt 2019] approaches to introduce students to contextualized tasks. Others have adopted collaborative learning to change the learning space to promote engagement [Gonzalez and Biørn-Hansen 2020].

Despite their value, most studies have focused on analyzing students' metrics (e.g., performance, pass rate) or their general impressions of a particular meaningful learning idea, usually collected at the end of the course. As a result, they have overlooked crucial aspects that emerge during students' learning processes, such as the relationships between students and the associations among the different pedagogical intervention elements and their effectiveness in sustaining students' learning in CS1.

Encouraged to contribute to the previous literature, we conducted an exploratory case study to trace and interpret the multiple learners' perceptions along a real-life undergraduate CS1 group ($N = 32$) regarding their learning experience in participating in a pedagogical intervention entirely planned on meaningful learning ideas. Hence, we collected data from learning journals (3 per student). Next, we conducted qualitative (coding, composite narrative) analysis procedures. As a result, the present work states the following research question:

> *Which elements of the meaningful learning-driven intervention, such as tasks and affective dimension, do students perceive as contributing to their learning experience?*

The present work has the following structure: In Section 2, we outline related works associated with our theme. Next, we introduce our theoretical framework in Section 3 and describe our method in Section 4. Subsequently, we present the work's results and corresponding discussion in Sections 5. Finally, we list some threats to validity (Section 6) and conclude this work by posing our concluding remarks (Section 7).

2. Related Works

To align with this work's focus and space constraints, we will specifically highlight representative studies that explore the teaching of CS1 curricula based on critical ideas of meaningful learning (Section 3) at the undergraduate level.

Some works embraced contextualized tasks by using problem- or project-based tasks. The former refers to small groups of students that work together to solve single-subject problems [Souza and Bittencourt 2019]. The latter is rooted in multidisciplinary real-world situations that students must solve to create an authentic product gradually [Chang et al. 2020] or at the end of the course. In contrast, other works moved beyond coding practices and opted for writing-to-learn tasks to encourage students to reflect on their learning experience [Stone and Cruz 2020].

Considering another perspective, some studies adopted pedagogical designs that change the learning environment. For example, particular works adopted collaborative approaches to foster a social construction of programming knowledge [Gonzalez and Biørn-Hansen 2020]. In contrast, others integrated cognitive and emotional dimensions to offer a supportive learning environment to alleviate negative emotions [Borovina Josko 2021] or used music to promote well-being [Borovina Josko and de Assis Zampirolli 2022].

Concerning instructional material, the literature provides cases of different approaches to help students digest programming content. For example, some works used comics [Suh et al. 2021] or lived coding [Lin et al. 2022] to discuss their aim. Others used simple code examples and content integration to present concepts [Berssanette and Francisco 2018].

The present work provides an opportunity to contribute to the literature by revealing the students' learning experiences reported at three different moments of a meaningful learning-oriented CS1 course. These reports allowed students to make sense of their cognitive and emotional experiences as close as possible to the proposed tasks' resolution moments.

3. Theoretical Framework

Section 1 discussed the dynamic of learning programming through the eyes of Ausubel's meaningful learning theory. According to it, learners intentionally integrate new information into their prior knowledge and experiences through cognitive thinking, which promotes comprehensive and lasting knowledge [Ausubel 2012].

However, operationalizing Ausubel's theory can be challenging for tutors, who can only manipulate the organization of concepts. Human constructivism theory supports overcoming this challenge by considering assessment strategies that encourage critical thinking to achieve competence (not just grades). This theory also recognizes that knowledge construction is associated with emotional aspects, cooperation, and contextualized tasks [Novak 2010].

Given the multidimensional nature of learning (mind-emotion-social), we explored theoretical works [Novak 2010, Ausubel 2012, Novak and Gowin 1984] to gather the main principles of meaningful learning (Table 1), which are essential for planning our pedagogical intervention and data analysis step.

Idea	Meaning
Action towards learning	Involves successive steps of information manipulation (e.g., discovering, relating, trying, applying) until gaining an accurate understanding, according to an intention of learning
Constructive Collaboration	Refers to the experience of discussing and evaluating the different ideas and perspectives of colleagues to approach a given problem
Contextualized Tasks	Connects tasks to some meaningful natural world situation
Emotions	Refers to three main aspects: the sense of fulfilment with the achieved goals or learning experience, the emotional commitment to learning, and the negative emotions (e.g., anxiety) that hamper meaningful learning
Intention of learning	The deliberate choice to integrate new ideas into previous knowledge and achieve personal learning goals
Logical Constructive Tasks	Refers to tasks that allow accommodation of new concepts based on their relationship to previous concepts
Logical Instructional Material	Material that illustrates the relevant concepts and ideas of some learning unit using nonarbitrary relationships
Reflection	Explores the own learning process characteristics (e.g., actions, approaches) and reflects on them and their possible effects

Table 1. Meaningful Learning Principles

4. Method

We used Fink's [Fink 2013] course design model as a comprehensive guide to introduce meaningful learning ideas into our pedagogical approach. In the following sections, we discuss the critical point of our planning and the data collection and analysis.

4.1. Our Context

Students receive an interdisciplinary education during their first year and a half at our university. This foundational knowledge prepares them for their chosen academic units (e.g., Information Engineering), which they select at the end of their second year. As part of this interdisciplinary education, all students take CS1, a 12-week programming course designed to teach programming fundamentals to a heterogeneous cohort. The course is taught via theoretical and lab classes (equally emphasised) and has a historical dropout of 25% at our university.

4.2. Learning Goals and Tasks

After considering our context, we began defining the course learning goal that prioritizes students' ability to transfer their programming knowledge to new and authentic situations in line with the *contextualized task* idea (Table 1). First, we selected authentic problems from various knowledge areas and daily life situations to achieve this goal. Then, we shaped them into tasks according to the topic of each of the ten units. We also connected each task with relevant Web material (e.g., news, white paper, short video) to emphasize the authenticity of the tasks.

Built upon our previous work information [Borovina Josko 2021], we assigned three mandatory and distinct problem tasks per week (for a total of 10). The difficulty of the tasks increased gradually as we considered the association of new concepts to the previous one (e.g., single to nested if). This approach was in line with the *logical constructive task* idea (see Table 1) and allowed for the establishment of a continuum that enabled learners to transfer knowledge to different problems [National Academies of Sciences et al. 2018].

We established criteria that focused on their functional coverage to evaluate students' solutions. This strategy served two purposes: to gauge how much of each problem the students were able to solve and to avoid not crediting partially correct answers. For more information about our evaluation criteria and formative feedback, please refer to [Borovina Josko 2021].

4.3. Instructional Material and Teaching Approach

To facilitate students' connection and retaining of new programming concepts, we developed logical and incremental instructional material (organized into units) based on the learning objectives outlined in Section 3 and *logical instructional material* idea (Table 1). We start with a household finances story featuring a cartoon character to set the stage for each unit. This story helps students grasp the programming concepts' limitations learned in the previous unit and prepare for a new one.

Next, we introduced each unit's new concept by providing examples and in-class exercises based on simplified real-world problems, illustrating (through the decomposition technique) how the new programming concept can help solve them. These problems gradually increase in complexity, allowing students to distinguish between them progressively while staying connected to the main idea of the concept. Finally, at the end of each unit, we revisit the household story and develop a solution using the new concept learned, reinforced by the decomposition technique.

Beyond material and task characteristics, we were concerned with the *emotional* aspects of students learning to program (Table 1). In response to negative emotions, students lack confidence and motivation and often resort to memorization strategies to pass exams, which are ultimately ineffective [Ausubel 2012]. Therefore, we fostered an open, respectful, friendly, and supportive learning environment that emphasized positive emotions and motivation to address this issue. In addition, we considered affective aspects related to the tutor's communication style, including body language, tone, and approachability. This approach is supported by the theory of embodied cognition, which suggests that the sender's body and tone of expression of emotion can facilitate comprehension [Niedenthal 2007].

Finally, we stimulated the pair working among students to sustain our intervention *constructive collaboration* aspect. This stimulus occurred during the immersion class in the first week and in the student-tutor contacts, where we encouraged their interdependence and ideas exchange to reach consensual solutions to the tasks. However, as we know this approach's limitations, we intend to improve our intervention in promoting collaboration among learners.

4.4. Learning Journal Design and Scaffolding Cycle

A learning journal is a tool that encourages students to *reflect* on their learning process, turning the challenges faced, strategies used, achievements, and emotions experienced during it visible. This understanding is crucial to promote student self-awareness [Moon 2006]. We explored aspects of the journal to overcome students' struggle to produce it for various reasons.

To allow students to express themselves freely, we opted for a freeform style journal (e.g., handwriting, video, storytelling) that emphasized their thoughts and feelings over grammar. Additionally, to balance the workload of students and the tutor, we decided on three learning journals of around 2700 words each. This approach allowed us to capture three crucial moments in the course: the beginning, the climbing phase, and the peak.

Moreover, we applied a journal writing cycle to help students improve their writing and enhance learning outcomes. The cycle consisted of three stages: immersion, week-long support, and submission analysis. The immersion stage (first week) aimed to familiarize students with the characteristics of journal writing using a 25-minute video based on the work of [Moon 2006].

For the remaining weeks, we provided weekly structured guidance on students' writing through various channels, such as in-person meetings and synchronous sessions. In addition, after each learning journal submission, we analyzed the content and provided individual feedback to engage students, encourage reflection, and request further information when needed. It is worth underlining that none of the students had previous experience writing learning journals or reflecting on their study approaches.

4.5. Data Collection

The present work utilized the learning journals submitted by students and their pre-course survey answers as data sources. The survey collected demographic information, invited the students to join the research freely and informed them about all data privacy procedures and possible research benefits. Moreover, we clarified that the participants would be known only at the course's end.

In 2022, we ran a CS1 course with 43 students enrolled. Of these, 22 were male (51%), and 11 were female (26%) who completed the course. The students' average age was 18.6 years old ($STD = 1.12$), and their final grade was 8.23 out of 10 ($STD = 1.32$). Approximately 39% of the learners had some previous contact with programming during high school, and ten students (23%) dropped out prematurely in the second week.

Almost all participants who completed our course produced all three learning journals except one who submitted only one. Consequently, we had ninety-six valid learning journals to analyse with approximately 2400 words (STD=241). Regarding the tasks, participants submitted all ten tasks, of which 7% were written in Python and the remaining in Java.

4.6. Analysis Process

Our study involved a rigorous three-stage process comprising data management, reduction, and analysis. In the data management stage, we prepared and organized all learning journals in a qualitative data analysis tool. In the data reduction stage, we used this tool to support our 3-round coding process of all learning journals using simultaneous Process Coding to identify a set of codes based on the students' actions and Subcoding to identify the referred actions' object.

We then used these methods in the first round to infer the corresponding codings. In the second round, we carefully reread all the learning journals to examine the alignment between the significance of the students' excerpts and the related codes. In the final round, we randomly invited two participants per journal with no overlap to validate our coding interpretations of their journals. Participants received explanations of the validation process and the codes' meanings before analyzing our coding inferences. As a result, they agreed with 88% of the codes without requiring adjustments, while the remaining 12% required adjustments to the coded excerpt length or the code assigned to an excerpt.

As only one researcher was involved, we did not use InterCoder Reliability in this study. Instead, we utilized other elements that characterize good qualitative work, including transparency in disclosing all methods and rules employed, attention to deviant cases, analysis of a feasible number of journals to allow for in-depth analysis, and use of students' perceptions in the discussion of results [O'Connor and Joffe 2020].

Finally, in the analysis stage, we followed a 2-round approach. In the first step, we reread all coded student commentaries to examine whether their meaning and connotation connected to the meaningful learning ideas expressed in the theoretical framework (Table 1). Then, in the second round, we randomly selected samples of student commentaries for each idea and combined them into single composite narratives. This approach allows for a concise description of findings while maintaining participant anonymity for a broad audience.

5. Results and Discussions

We implemented many meaningful learning principles, which our students reported positively impacting their learning experience and ability to construct knowledge. Figure 1 displays the students' perceptions of their learning experience throughout the course, as documented in their journals.

Code Category	Code Item	Journal 1	Journal 2	Journal 3	Grand Total
General	(a1) Being grateful for the Learning Experience	6	4	15	25
	(a2) Recognizing the assessment criteria as fair	2	1	1	4
Actively finding and evaluating information about a topic	(b1) Reading Books	1			1
	(b2) Reviewing the Lectures Materials	16	14	9	39
	(b3) Reviewing the Web Materials	9	8	2	19
	(b4) Reviewing with the professor or assistants	5	3	1	9
	(b5) Testing fragments of code	1	3		4
	(b6) Using Notes	4	3	2	9
Actively understanding a task problem	(c1) Discussing with Friends	13	8	11	32
	(c2) Discussing with the Assistant	2	5	4	11
	(c3) Discussing with the Professor	3	6	5	14
Actively Imagining a solution to a problem	(d1) Sketching a (possible) Solution	13	8	6	27
	(d2) Using trial and error looping	9	4	5	18
	(d3) Visualizing Code Behavior	3	5	5	13
Practicing (Doing) and Testing	(e1) Practicing (Doing) and Testing	17	12	15	44
Engaging on the tasks	(f1) Feeling emotionally involved with the tasks	13	6	6	25
	(f2) Progressing towards the goals	11	16	20	47
	(f3) Recognizing task relevance or value	12	15	18	45
Reflection	(g1) Recognizing inadequate or adequate approaches	7	12	8	27
	(g2) Reflecting on how to improve the learning process	2	1	1	4
Seeing the result	(h1) Feeling happy about the achievements	15	11	9	35
	(h2) Feeling happy by helping colleagues		4	5	9

Figure 1. Students' statements analysis per journal and unique coding

Further, we analysed the associations between our intervention principles and the students' perceptions that revealed a complex network of relationships illustrated in Figure 2. This figure shows directed arrows between nodes, with uncolored nodes representing the meaningful learning principles we introduced, green nodes representing other student-identified elements, and blue nodes referring to other supportive features introduced by this work.

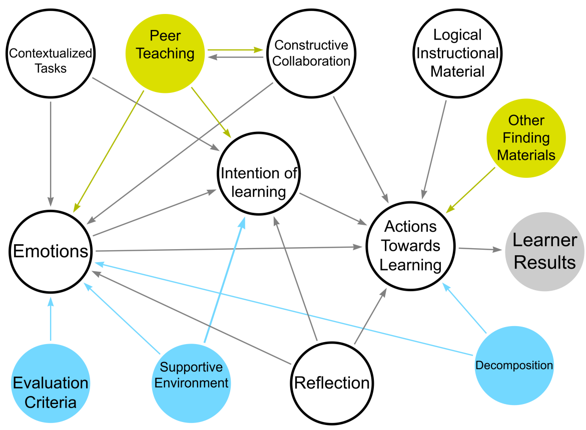

Figure 2. Net of influences between meaningful learning principles and other elements

Our investigation identified that crucial intervention components significantly impacted students' learning intention. Specifically, students reported that the practical pertinence of the contextualizing tasks ($f1 - f3$, Figure 1) was relevant in engaging and helping them connect programming concepts to real-world contexts. By doing so, students felt a sense of contributing to something meaningful, further enhancing their motivation to learn, as illustrated in the composite narrative below. This finding is consistent with prior research in CS1 courses [Souza and Bittencourt 2019, Chang et al. 2020].

> *The (lab) tasks' problems made me feel lively and want to solve new ones. Moreover, I felt curious and used what I learned recently in other courses I am taking. Therefore, even though I need more time to study programming, I can absorb all concepts I hardly forget because studying is active in this course.*

Furthermore, our analysis also revealed that incorporating learning journals was a valuable tool for students to reflect on their progress, achievements, and study strategies. Despite some initial skepticism, students appreciated the journal for raising their awareness, monitoring their problem-solving strategies ($g1$), and connecting their current state to personal matters for future development ($g2$), as demonstrated in the following narrative. This finding is consistent with previous research advocating writing as a tool for learning [Novak 2010, Bhardwaj 2020] and underlines its effectiveness when coupled with an appropriate scaffolding cycle. The favourable impact on student motivation and learning outcomes highlights the value of learning journals that should be deeply explored in the CS1 context.

> *By describing precisely my study tactics and how I developed the tasks, the journal helped me a lot in thinking about what I did that worked and what I should do in the future to improve. In contrast, I thought the writing was boring, but I understood the importance and tried hard to write it. Nevertheless, I confess that I will miss relating my experiences.*

Peer teaching also emerged as an effective tool for increasing students' motivation and sense of fulfilment. Indeed, students developed a stronger desire to improve their knowledge and skills by teaching their peers ($h2$), as shown in the following narrative.

> *Several places mention that the best way to learn is to teach, and I did notice that the more I attempt to help others, the more I learn. Indeed, helping my colleagues forces me to face my shortcomings and discover better ways to express my ideas clearly.*

This outcome highlights the potential for peer teaching to be a powerful means of engaging students in their learning process [Rusli et al. 2021]. It also can create a more dynamic and collaborative learning environment in CS1 courses. As Paulo Freire [Freire 2015] reminds us, "Those who learn, teach by learning". However, further study is needed to explore its full potential in CS1 courses.

Despite the significant impact of the intervention components mentioned earlier, our study revealed that emotions played a critical role in sustaining students' intention to learn. Throughout the course, several participants reported experiencing positive emotions, such as happiness ($h1-h2$), stimulation ($f1$), and gratitude ($a1-a2$), which further strengthened their commitment to learning. To illustrate, the following narrative highlights terms associated with satisfaction, humor, pride, gratitude, and curiosity. These findings align with prior research emphasizing the importance of emotions in creating a meaningful and impactful learning experience [Li et al. 2020, Novak 2010, National Academies of Sciences et al. 2018].

> *Despite the challenges and stress (due to my anxiety), we have found these last few weeks quite fun and satisfying. The lab practices are similar to real-world problems,*

which makes us more excited and willing to try to solve various problems with programming. I was never really interested in learning anything about computing, but now, at the end of our course, I am curious.

According to students, the opportunity to reflect on their learning through journal writing played a critical role in shaping their emotions and motivation. By reflecting on them, students felt a sense of pride in their progress and gained more confidence in their abilities. In other words, they connected their knowledge and ideas to an emotional component, as noted in previous research on meaningful learning [Novak 2010].

The supportive learning environment also significantly fostered positive emotions among students. According to students, the tutor's genuine interest in the course topics and their students' learning, and their friendly demeanor and enthusiastic approach contributed to them feeling cared for and motivated throughout the course ($a1$), as illustrated below. This outcome aligns with previous findings in psychopedagogy [Trigwell 2012] and ours [Borovina Josko 2021].

All my performance was thanks to your dedication, lovely didactic, and attention to conducting the course. You led us in a way that the student could learn, see their mistakes, analyze their performance, and have the chance to improve. Finally, your lectures were always fun and relaxed, and the tasks were consistent with the content studied.

Interestingly, some students felt fairly assessed by our criteria ($a2$). This outcome supports the suggestion by [Gibbs 1999] that criteria can lead to anxiety, highlighting the importance of further investigation into how evaluation practices can impact student emotions and motivation.

All the elements discussed so far have engaged students towards learning by fostering an active "finding-understanding-imagining" actions towards learning. By utilizing various study strategies and resources, students could overcome learning obstacles. In particular, students found our instructional material ($b2$) more helpful than web resources ($b3$) in finding information about a topic. The material's logical organization and clear presentation made it easier for students to understand programming concepts and relationships, which aligns with prior neuroscience research [National Academies of Sciences et al. 2018]. Sadly, the traditional book ($b1$) was the least utilized resource, suggesting that newer learners prefer multimedia and immersive environments over static resources. The narrative below illustrates the discussion above.

Understanding the basics of a programming language and using it was challenging, but the several examples in the lectures were beneficial. Their different situations expanded the circumstances in which the knowledge acquired in the last few weeks could be used.

Regarding the understanding step, our study found that constructive collaboration ($c1-c3$, $b4$) was a critical study approach. By considering similarities and contrasts between their colleagues' ideas or the tutor's insights, students could enhance their understanding, encourage knowledge-sharing (leading to peer-teaching in some cases) and foster positive emotions (e.g., gratification, empathy) through social interactions. These findings are consistent with prior research on knowledge construction through social interactions in CS1 courses [Bhardwaj 2020, Borovina Josko 2021]. The following narrative exemplifies the discussion above:

Chatting with colleagues' was essential as it brought us closer. In addition, the discussions during the lesson between the tutor and us generated great tips that made solving the problems of the next task easier. Likewise, the tutor chat was crucial as his insights and feedback improved my problem-solving approach.

In the imagining step, our instructional approach encouraged students to plan their solutions ($d1 - d3$) before coding using decomposition. Many students reported experiencing the benefits of this technique, including reducing stress and frustration. In addition, providing a "road map" for novices on approaching programming problems supported students in transferring their knowledge to new tasks, as noted in previous studies [National Academies of Sciences et al. 2018].

Lastly, we observed that students did not explicitly recognize the idea of logical constructive tasks (Figure 2), even though they did follow this idea while completing the tasks. We have two possible explanations for this result: (i) the tasks did not establish a strong connection between new and old programming concepts, or (ii) the other principles and elements of our intervention overshadowed this. While the absence of this idea in the graph is concerning, further investigation is necessary to understand this issue entirely. We must examine the tasks more closely to determine whether they effectively established a strong connection between new and old programming concepts.

6. Threats to Validity

Our learning journal material provided examples of both practical and ineffective content. The provision of these examples may have led some students to write what they thought the tutor expected to see. Additionally, it is worth noting that this study was limited to a single group of students whose traits may not reflect the experiences of a broader population.

7. Conclusion

This study aimed to evaluate the impact of our pedagogical intervention in promoting meaningful learning among CS1 students. We analyzed 96 learning journals and found that the intervention successfully improved the learning outcomes of the 32 participating students. Such results highlight the importance of adopting a comprehensive approach to teaching CS1, which includes the design and integration of instructional materials, teaching methods, in-class activities, and a supportive environment that addresses students' cognitive and emotional needs. In addition, future research will investigate the impact of students' characteristics and socio-cultural-economic background on the effectiveness of meaningful learning-based interventions. By doing so, we can better understand how to design effective interventions tailored to the unique needs of different student populations.

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