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Integrating Design Thinking and Problem-Based Learning in MOOCs

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ABSTRACT

This article presents our findings concerning a MOOC named 'Introduction to R programming language', in which we applied design thinking combined with problem-based learning to enhance student engagement and improve the learning experience. The course was delivered to 575 students from Brazil between February 28 and March 18, 2022. Our goal was to analyse the design and implementation of this program quantitatively and qualitatively. We followed a design-based research approach and collected quantitative and qualitative data through questionnaires. The quantitative data were analysed using descriptive statistics, while the qualitative data were processed using the five-phased language processing method (Yin, 2015). The main findings are as follows: 1) The use of personas enhanced the design and delivery of a course aligned with students' interests. 2) The problem-based learning approach supported students' engagement and enhanced their learning experience.3) Demonstrating empathy, thoughtfulness, and providing swift feedback served as motivators for the students. These findings suggest that the synergistic application of DT and PBL creates a pathway towards alignment between course design and learner needs while also helping to support student motivation, engagement, and perseverance in online learning environments. While this approach demands a significant investment of time and effort from instructors, the educational benefits for learners are substantial and promising for future MOOC development.

KEYWORDS

design thinking, problem-based learning, mooc, persona, design-based research.

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INTRODUCTION

The professors from the Federal University of São Paulo (Unifesp) occasionally offer free online extension courses. These courses aim to give educational opportunities to both university students and the broader community. Anyone interested in taking extension courses is allowed to enrol, if he/she meet the enrollment requirements. The professors involved do not receive any financial compensation for delivering this kind of course. However, the work brings research opportunities and counts toward the professor's career progression. The professors who offer this kind of course are usually those interested in promoting knowledge sharing in the communities. In this article, we discuss the lessons learned while creating and delivering a massive open online course (MOOC) named 'Introduction to R programming language'. This course was offered during the first semester of 2022 to 575 students from all over the country. This MOOC was designed and delivered by combining design thinking concepts and a problem-based learning approach

LITERATURE REVIEW

Massive Open Online Courses (MOOCs) have revolutionised education by making high-quality learning materials accessible to a global audience. However, despite their potential, MOOCs face a persistent challenge: low student engagement and high dropout rates. Research indicates that MOOC completion rates often fall below 10% (Jordan, 2014; Onah et al., 2014; Gü & Cagiltay, 2024), raising critical concerns about their effectiveness in fostering meaningful learning experiences. One of the key reasons for this low engagement is that many MOOCs rely on passive learning models, where students consume pre-recorded lectures and complete assessments with minimal interaction (Bonafini, 2017). This approach fails to encourage active learning, critical thinking, and problem-solving—elements crucial for deep learning and sustained engagement (García-Martín & García-Sánchez, 2020). Given this challenge, researchers and educators have been exploring innovative pedagogical strategies to improve student motivation and retention in online courses.

Design Thinking (DT) and Problem-Based Learning (PBL) have emerged as two promising methodologies to enhance student engagement in MOOCs. DT is a human-centred and action-oriented approach to solving real-world problems (Brenner et al., 2016; Camacho, 2016). It focuses on addressing user needs while considering their context and limitations (Singh & Mishra, 2023), following a sequence of well-defined steps that lead to the development of a product or service through iterative prototyping (Verganti et al., 2021). The origins of Design Thinking can be traced back to fields such as engineering and architecture in the 1950s and 1960s (Luka, 2014). By the 1970s, its application had expanded into business, innovation, and service development (Johansson-Sköldberg et al., 2013). Today, DT is widely used in diverse fields, including education, where it helps instructors create learning environments aligned with students' needs and experiences (Auernhammer & Roth, 2021; Dorst, 2011; Noweski et al., 2012).

One of the most widely adopted frameworks for Design Thinking includes five stages: Empathise, Define, Ideate, Prototype, and Test (Wolniak, 2017). In the Empathise stage, user perspectives are explored through interviews, observations, and surveys (Jensen et al., 2016; Filatro & Cavalcanti, 2017), often leading to the development of personas—fictional characters that represent user profiles (Dahiya & Kumar, 2018). The Define and Ideate stages are used to structure content and generate course ideas tailored to learners' needs. In the Prototype and Test phases, educational solutions are developed, delivered, and refined based on feedback. DT has already proven effective in curriculum design, playful learning, STEM education, and teacher training programs (Pusca & Northwood, 2018; Panke, 2019; Henriksen, 2017; Llorent-Vaqueroa & Ortega-Tudelab, 2021; Dimitropoulos et al., 2022; Shé et al., 2022).

Problem-Based Learning (PBL) is a student-centred instructional method that engages learners in analysing and solving complex, real-world problems to stimulate critical thinking and problem-solving skills (Hmelo-Silver, 2004). In this approach, students collaboratively examine open-ended problems, identify what they need to learn, investigate possible solutions, and apply their findings to propose evidence-based responses (Nicholus et al., 2023). It fosters self-directed learning, collaboration, and reflective thinking—skills increasingly essential in 21st-century education (Tawfik, 2015). Traditionally implemented in group settings, PBL can be adapted for individual learners in self-paced contexts such as MOOCs (Verstegen et al., 2023).

Despite their individual benefits, DT and PBL each have limitations when used in isolation. DT supports user-centred course development but does not inherently promote inquiry-based learning or knowledge construction. On the other hand, PBL encourages deep engagement but may result in frustration if not supported by a well-structured design. Thus, integrating both methodologies can provide a balanced approach: DT ensures accessibility and relevance, while PBL enhances cognitive engagement and meaningful learning.

While both Design Thinking (DT) and Problem-Based Learning (PBL) have been widely recognised as effective educational approaches, their combined use in MOOC design remains underexplored. This study addresses this gap by investigating how integrating DT and PBL—particularly through personas, problem-based tasks, and empathetic instructor behaviour—affects student engagement, motivation, learning outcomes, and completion rates in large-scale online education, as well as the challenges involved in this integration.

In our MOOC on R programming, these approaches were combined. Personas were created based on student profiles collected via surveys. These personas guided the design of open-ended programming challenges tailored to learners' goals. Instructional/curricular problems encouraged creative coding solutions and real-world applications. Students were invited to share code in discussion forums, compare strategies, and receive feedback from peers and the instructor. Guiding questions also supported reflection and consolidation of learning.

The study addresses the following research questions:

1. How does the use of Design Thinking–driven personas in the design of an undergraduate STEM MOOC influence the alignment between course content and student interests?

2. How does the application of a problem-based learning approach influence course completion rates in a MOOC?

3. How do students perceive their engagement and the challenges of participating in a MOOC that integrates Design Thinking and Problem-Based Learning?

METHODOLOGY

Research design

We employed a design-based research approach (Figure 1) for this study. This intervention-focused research methodology connects theory and practice (Baumgartner et al., 2003; Reimann, 2010). It has been utilised in educational contexts to assess the efficacy of teaching and learning methodologies (Anderson & Shattuck, 2012).

The design-based approach typically initiates with problem analysis (in our case, developing strategies to make a MOOC meaningful to a broad and diverse audience). The researcher collects the data and conducts an analysis (in our study, we compiled and evaluated data concerning the enrolled students). Subsequently, the researcher devises a solution for the problem and implements it (in our investigation, we designed a MOOC structure tailored to the students' needs and conducted the course). The researcher subsequently assembles data about the solution's effectiveness, performs an analysis, and formulates conclusions.

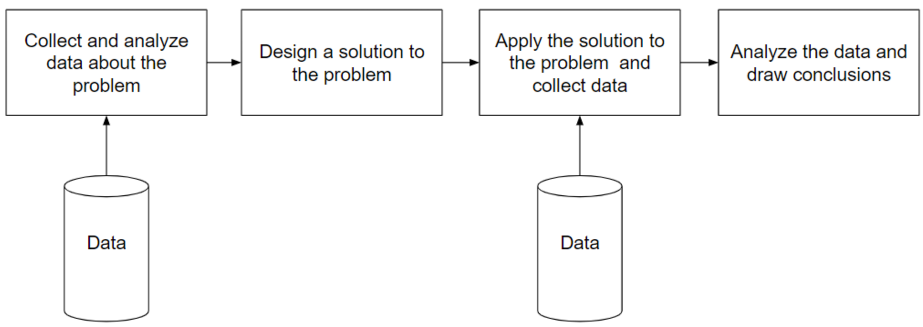

Figure 1: The design-based research approach (based on Scott et al., 2020)

Participants

A total of five hundred and seventy-five (575) individuals enrolled in the course, with 306 being females (53%) and 269 being males (47%). Ninety-eight per cent (98%) of the students originated from 25 out of the 26 Brazilian States, as there were no students from the State of Amapá. The predominant proportion of students were from the State of São Paulo (61%), followed by the States of Minas Gerais (7%), Rio de Janeiro (6%), Rio Grande do Sul (4%), Pará (4%), Paraná (2%), and Distrito Federal (2%). The remaining states accounted for 1% of enrolled students. An additional two per cent of students (9 students) resided in other countries, including Germany, Canada, Colombia, the United States of America, Guiné-Bissau, England, Paraguay, Uruguay, and Portugal.

The youngest student was 17, while the oldest was 69. The mean age was calculated to be 32.3 years, with a median age of 30. The interquartile range spanned 15 years, and the standard deviation was recorded as 10.1 years.

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Data collection procedures

The study employed two complementary units of analysis. Objective indicators of engagement included course completion rates and exam scores. Subjective data were derived from participants' self-reported perceptions of the course materials, instruction, and learning experience. These perception data were used to explore students' experiences but not as direct measures of engagement.

The data were collected through two questionnaires and a virtual exam (a multiple-choice test). The initial questionnaire was dispatched one week before the course's commencement. It encompassed 15 closed-ended questions and one open-ended question (Appendix A). The objective of the closed-ended questions was to obtain data on students' age, gender, educational background, work experience, field of occupation, familiarity with programming in R, motivations for enrolling in the course, and their learning aspirations from the course. The insights from this questionnaire played a pivotal role in shaping the personas, which subsequently guided our course design.

The second questionnaire was distributed at the end of the course. Its purpose was to collect data regarding the students' perspectives on the course's structure, their learning experiences, and their overall evaluation of the course. This questionnaire (Appendix B) featured three closed-ended questions on a three-point Likert scale, along with an open-ended question.

The virtual exam (Appendix C) comprised 10 closed-ended questions designed to quantitatively assess students' comprehension of coding with R. Additionally, we collected data on the time the instructor invested in the course's development and delivery.

Data analysis procedures

Student engagement was operationalised through both objective and subjective benchmarks. Objective benchmarks included course completion rates and exam scores, compared to institutional averages for similar MOOCs. Subjective benchmarks were based on participants' self-reported perceptions of engagement, motivation, and satisfaction collected through post-course surveys.

For the analysis of quantitative data, we employed descriptive statistics. The necessary calculations were conducted in R, which also facilitated the creation of graphs to represent the results visually.

As for qualitative data, we employed the five-phase language processing method outlined by Yin (2015). Initially, we compiled responses to the open-ended questions from both the pre-course and post-course questionnaires (Appendices A and B). We then disassembled the data into smaller meaning units—individual phrases or sentences expressing a single idea. Next, we coded these units manually, assigning short descriptive labels that captured the main concept or sentiment expressed. During reassembly, we grouped related codes into broader categories (supercodes) to identify recurrent patterns. From these categories, we derived themes that encapsulated the key aspects of students' perceptions and experiences. Finally, we interpreted these themes in relation to the quantitative results, seeking points of convergence and divergence between the two data sources. No CAQDAS software was used.

THE COURSE DESIGN AND DEVELOPMENT

Over a month, the course was developed following the five-stage design thinking process.

The Empathise Stage

We administered a questionnaire to all students who had registered to take the course one week before its commencement. The questionnaire was designed to gather demographic information about the students and insight into their motivations for taking the course. The responses were compiled and stored in a file named "enrollment data."

Subsequently, we analysed the enrollment data using descriptive statistics and a persona-based analytical approach (Miaskiewicz & Kozar, 2011). Personas were developed to represent prototypical student profiles based on common patterns in motivations, prior experience, and learning goals. This method allowed us to synthesise demographic and motivational data into coherent learner categories, facilitating the interpretation of participants' diverse backgrounds and expectations. This analysis enabled us to identify three distinct personas.

Persona 1 – Undergraduate Student

This persona represents individuals at the beginning of their academic and professional journeys. To construct it, we applied descriptive statistical filters to the enrolment data, isolating participants who identified themselves as undergraduate students. This subgroup comprised 166 individuals, representing 28.9% of the total enrolment's group which was was predominantly female (58%) and relatively young, with an average age of 24 years. About half had no prior work experience, while 23% reported between one and five years in the job market.

In terms of academic background, most participants had little or no previous exposure to programming in R—38% reported no knowledge and 49% very little. Furthermore, 42% were simultaneously enrolled in other courses, suggesting limited available study time. Their primary motivation for enrolling was to acquire foundational technical skills and gain a competitive advantage at the start of their careers. Many (77%) also viewed obtaining the course certificate as an important credential to include in their academic or professional portfolios.

Persona 2 – Teacher

This persona encompasses participants working primarily in educational or research-related fields who possessed graduate-level education (master's or doctorate) or identified themselves as graduate students. This subgroup comprised 240 individuals, representing 41.7% of the total enrolment.

The group was predominantly female (58%), with an average age of 36 years. Many were professionals in Health Sciences (32%) or Biological Sciences (20%), and 41% had more than ten years of work experience, often combining teaching and research responsibilities.

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Most participants had limited prior experience with R, with 32% reporting no knowledge and 49% very little. In addition, 45% were working full-time while taking the course, and 41% were enrolled in other academic programs, highlighting heavy professional and academic commitments.

Their motivation was strongly tied to applying data science concepts in their teaching or research, rather than acquiring programming skills per se. Most (99%) believed the course would support their professional development, and 88% indicated it was directly relevant to their ongoing research projects.

Persona 3 – White-Collar Worker

This persona represents professionals from corporate, technical, or applied fields who reported holding an undergraduate or MBA degree. These individuals were distinct from the Teacher group in that they worked outside academia, typically in business, engineering, or applied sciences. The subgroup comprised 156 participants, representing 27.1% of the total enrolment.

The group was predominantly male (58%), with an average age of 35 years. Many worked in Exact Sciences (32%), Engineering (15%), or Social Sciences (14%), and 53% had less than ten years of professional experience.

Most participants had limited prior experience with R—33% reported no prior knowledge, and 51% reported very little. Additionally, 40% were working full-time while taking the course, and 42% were simultaneously enrolled in other educational programs, reflecting competing professional and learning priorities.

Their primary motivation was to strengthen their analytical and data-driven decision-making skills to enhance their career advancement. Many (70%) also viewed the course as directly applicable to their daily work tasks, particularly in data analysis and performance reporting.

The three personas—Undergraduate Student, Teacher, and White-Collar Worker—represent the main learner profiles identified in the course, each reflecting distinct stages of professional development and different motivations for participation. These personas are fictional yet evidence-based representations of participant subgroups, developed through the synthesis of demographic, professional, and motivational data. They do not depict real individuals but rather illustrate common patterns and tendencies observed in the dataset. As analytical tools, personas help make complex quantitative and qualitative data more accessible and interpretable, offering a clearer understanding of how different learner profiles engaged with the course. While they inevitably simplify diversity within each group, their purpose is to highlight key differences across major participant categories rather than to serve as exhaustive or definitive classifications.

Table 1 summarises the key characteristics and differentiating features of these personas.

Table 1: Distinction Among Personas

Persona	Profile Description	Main Context	Primary Motivation
Undergraduate Student	Individuals at the beginning of their academic or professional journeys.	Enrolled in undergraduate programs; limited work experience.	To learn foundational technical skills and obtain credentials that enhance employability.
Teacher	Experienced professionals working in education or research, typically with graduate degrees.	Academic or research institutions often balancing teaching and scholarly activities.	To apply R and data science concepts to teaching and research for professional growth.
White-Collar Worker	Professionals from corporate, technical, or applied fields with undergraduate or MBA degrees.	Non-academic work environments such as business, engineering, or applied sciences.	To use data analysis for practical, career-oriented purposes—improving performance and advancing professionally.

The Define Stage

Throughout the Define Stage, we examined the three personas, analysing their shared characteristics and differences. Our conjecture for Persona 1 (the undergraduate student) was that they would exhibit interest in learning mathematical operations in R, intending to apply this knowledge in other academic courses. For Persona 2 (the teacher), we hypothesised that they would express interest in acquiring the skills to develop educational applications—simple programs that could be implemented within their classrooms. Furthermore, we speculated that Persona 3 (the white-collar worker) would be interested in acquiring the ability to manipulate database data. Consequently, we decided to structure our course into three distinct modules, each addressing a specific need associated with these personas (see Table 2).

Table 2: Addressing the personas' needs.

Persona	Persona's hypothetical need	Modules to be developed to address the persona's needs
Undergraduate student	• Basic programming knowledge • Mathematical operations with R	Module 1: Basic concepts
Teacher	• Basic programming knowledge • Creation of applications to be used in the classroom	Module 2: Development of educational applications
White-collar worker	• Basic programming knowledge • Data manipulation	Module 3: Data manipulation

The Ideate Stage

During the Ideate Stage, we evaluated two potential Virtual Learning Environment (VLE) solutions for structuring the course (see Table 3). The initial option involved using Moodle as the Learning Management System (LMS) and adopting an auto-instructional approach—a self-guided structure with no course instructor. Selecting Moodle offered numerous benefits, given its built-in functionalities, including collaborative tools, a file management system, and calendars. Nonetheless, it required self-funding, as university financial support was unavailable. The auto-instructional approach was set to simplify course delivery and management, focusing on video lectures and assessments. However, this approach would limit students' active learning, as it lacked opportunities for problem-solving and practical application.

The alternative solution proposed combining Google Classroom and Google Sites as virtual learning environments, integrated with problem-based learning (PBL) as the educational methodology. While Google Classroom offers fewer features than Moodle, its synergy with Google Sites enhances functionality and flexibility, mitigating several limitations typically encountered in Moodle-based courses. Moreover, since Unifesp already supported Google Classroom institutionally, this solution incurred no additional costs.

Opting for PBL ensured an experiential, student-centred learning experience, encouraging learners to solve authentic problems using R programming. However, this model required active instructor participation—including designing problem scenarios, guiding group discussions, providing formative feedback, and assisting students in debugging and refining their code.

After comparing both alternatives (Table 3), we selected this option because it aligned more closely with the course's pedagogical objectives of engagement and applied learning. Although it demanded greater instructor involvement, the approach offered higher pedagogical value, fostering deeper learning, collaboration, and real-world skill development among participants.

Table 3: The possible VLE solutions

	Possible Solutions	Advantages	Disadvantages
Solution 1	VLE: Moodle Educational approach: Auto-instructional	VLE had a large number of functionalities	Costs The students would not have hands-on experience
Solution 2	VLE: Google Classroom and Google Sites Educational Approach: Problem-based learning	No costs The students would have hands-on experience	Teacher's workload VLE had limited functionalities

The Prototype Stage

In the prototype stage, we expanded the preliminary course structure defined during the Ideation stage (see Table 2), transforming the initial module titles into detailed instructional content. We developed a prototype version of the course within the Virtual Learning Environment (VLE), which also included a dedicated website hosting the video lectures. Each module was organised into multiple topics, each supported by a series of brief, focused video lessons. These lectures were intentionally concise—ranging from 5 to 10 minutes—to accommodate the diverse needs of learners. This decision was guided by insights from the personas, which revealed that many students faced time constraints due to multiple course enrolments or concurrent professional commitments. Anticipating the risk of digital fatigue in online learning environments (Inan et al., 2024) and limited study time, we adopted a microlearning approach using short videos to enhance accessibility and engagement.

Since we followed a problem-based learning approach, we decided that at the end of each topic, students would face a challenge—a practical exercise that would give them the opportunity to code a small program.

Furthermore, each module concluded with a "Challenge of the Week" that required students to develop an additional program. These challenges were intentionally designed to be more complex than the standard exercises, serving as in-depth reviews of previously learned concepts and providing opportunities for extended practice. Each challenge aimed to be both engaging and rewarding, allowing students to experience a sense of achievement through creative problem-solving. In the final week, students completed a comprehensive version of the Challenge of the Week, which served as the final exam and consolidated all the material taught throughout the course. Refer to Table 4 for a comprehensive presentation of the modules, topics, problem-solving tasks, and weekly challenges.

Table 4: The course modules, problems, and challenges of the week

Course Module	Topics	Problem	Challenge of the Week
Module 1: Basic concepts	Topic1: RStudio IDE (Integrated Development Environment) Topic2: Data types, coercion rules, functions and arguments Topic 3: Functions	Create a program that asks the user his/her first and family name, create the full name and output it on the screen	Create a times table program that helps a child to learn how to multiply two numbers.
Module 2: Development of educational applications	Topic1: vector, matrices, factors, lists Topic 2: Loops, conditionals and logical operators Topic 3: Local and global variables	Create a program that allows the students to encrypt and decrypt a message.	Create a program that helps a child to learn the Portuguese language accentuation rules.
Module 3: Data manipulation	Topic1: creation and manipulation of data frames using the package tidyverse Topic 2: Creation different types of graphs (scatter plot, histogram, boxplot)	Create a program for an animal shelter that allows the user to make queries about the animals available for adoption.	Create small programs to answer ten questions related to the topics covered during the course; this activity served as the final exam.

During this stage, we developed the course website using Google Sites, set up the Virtual Learning Environment (VLE) in Google Classroom, and produced 72 video lectures using Loom, a video creation and sharing tool that enables users to record their screen, webcam, and voice simultaneously.

The website included pages hosting the course syllabus, video lectures, problems, and the Challenges of the Week. It also featured a resources page with links to 39 Open Educational Resources (OERs)—freely accessible online books on R programming. Furthermore, the course website itself was designed as an OER, providing open access to its structure and content for reuse and adaptation by other educators. We estimated that completing all course activities would take approximately 56 hours. For a visual depiction of the course's learning environment, please refer to Figure 2.

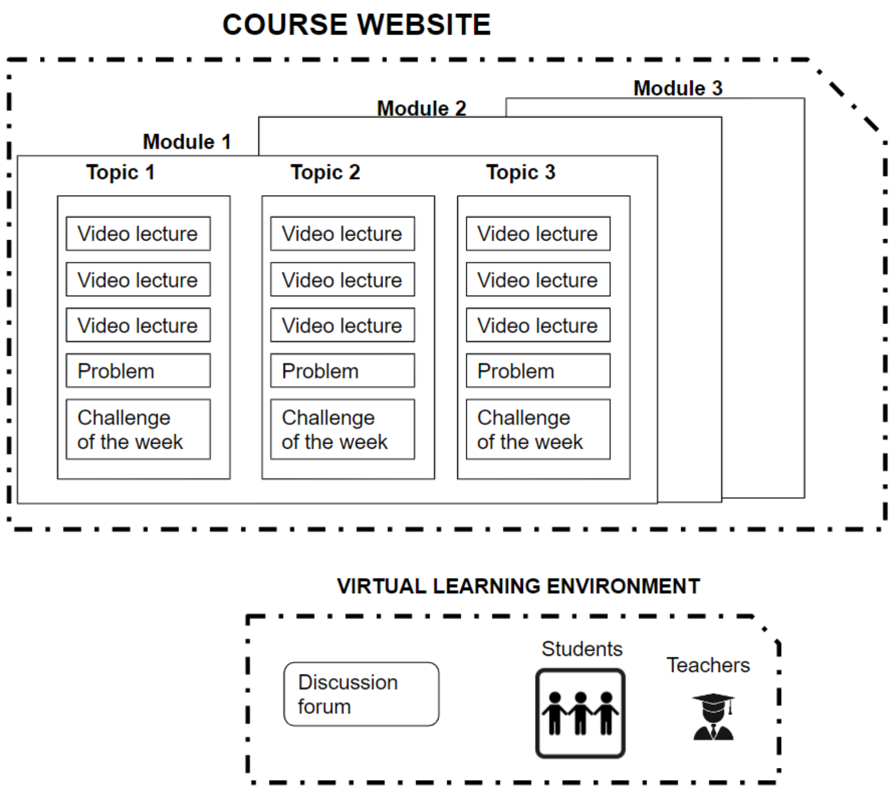

Figure 2: The structure of the virtual learning environment.

The Test Stage

During the Test Stage, we delivered the course and gathered data on students' perceptions of the course. The course delivery spanned three weeks.

Based on the persona analysis, we found that most participants lacked prior programming experience and were simultaneously enrolled in other courses. Consequently, we anticipated that they might face difficulties in developing computational reasoning skills and could experience frustration or stress. To mitigate this risk and prevent dropout, we adopted an empathy-driven instructional approach, consistent with the principles of design thinking.

In this context, empathy referred to a deliberate effort to understand students' perspectives, emotional states, and learning challenges, and to adapt our communication and support strategies accordingly (Adrup et al., 2022). This went beyond conventional instructor responsiveness: we personalised feedback, acknowledged students' struggles, and explicitly validated their learning efforts.

We regularly monitored the discussion forum—often several times a day—to provide timely and reassuring guidance. In addition to written replies, we created short video responses demonstrating the steps to solve specific problems, helping students feel supported and capable of overcoming difficulties. We also made ourselves available by email to ensure that no question went unanswered. Despite our heavy workload, we maintained this empathetic stance throughout the course, aiming to foster a sense of connection and belonging among participants.

Additionally, we administered a virtual final examination consisting of ten questions (Appendix C), each requiring students to design and execute a small program. The exam was conceived as a problem-based learning (PBL) activity, fully aligned with the course's instructional approach. Rather than serving solely as an assessment tool, it provided students with a meaningful opportunity to apply the knowledge and skills acquired throughout the course, reinforcing their learning through authentic problem-solving tasks.

Towards the end of the third week, we administered a questionnaire to the students to capture insights into their perceptions of the course structure and learning experience. We employed this questionnaire to assess whether the course's structure and delivery aligned with the students' requirements. At the end of the course, we analysed the data compiled during this phase and formulated conclusions, which are subsequently expounded upon in this article.

RESULTS

Quantitative Results

Data Related to the Students' Perceptions of the Learning Resources

Figure 3 presents a divergent stacked chart illustrating the results for the three questions related to learning resources: the quality of the lectures, the difficulty level of the video lectures, and the difficulty level of the proposed problems. Responses were categorised into three levels—1 (Low), 2 (Medium), and 3 (High)—represented respectively by orange, grey, and blue-green in the figure.

Eighty-six per cent (86%) of the students rated the quality level of the video lectures as high. Regarding the difficulty level of the video lectures, 57% of the students rated it as low, and 41% as medium. Regarding the difficulty level of the proposed problems, most students (77%) classified it as medium, 19% as high, and only 4% as low.

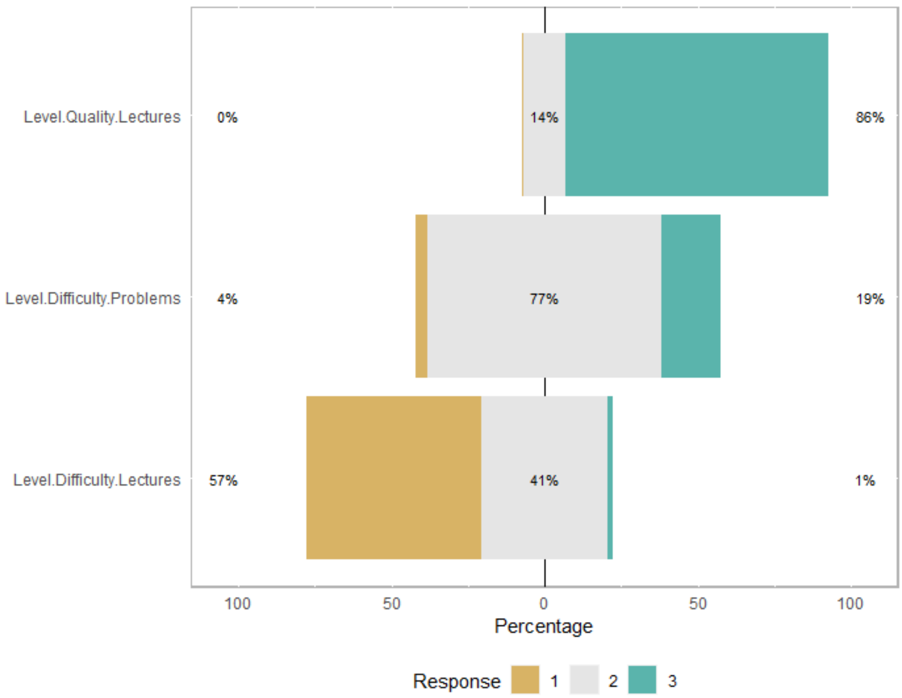

Figure 3: Students' perceptions of the learning resources.

Data Related to the Students' Perceptions about their Learning

Figure 4 presents a divergent stacked chart showing the results of two inquiries on students' prior familiarity with the R programming language and their learning experience at the end of the course. Responses were categorised into three levels—1 (Low), 2 (Medium), and 3 (High)—represented respectively by orange, gray, and blue-green in the figure.

At the outset of the course, students self-reported their prior familiarity with R, and at the end, they self-assessed their learning experience. The results indicate that, before the course, most students (63%) reported a low level of prior knowledge, 34% reported a medium level, and only 3% reported a high level. By the end of the course, 48% of students rated their knowledge as high, 47% as medium, and only 5% as low, demonstrating a clear self-reported improvement in their perceived understanding of R programming.

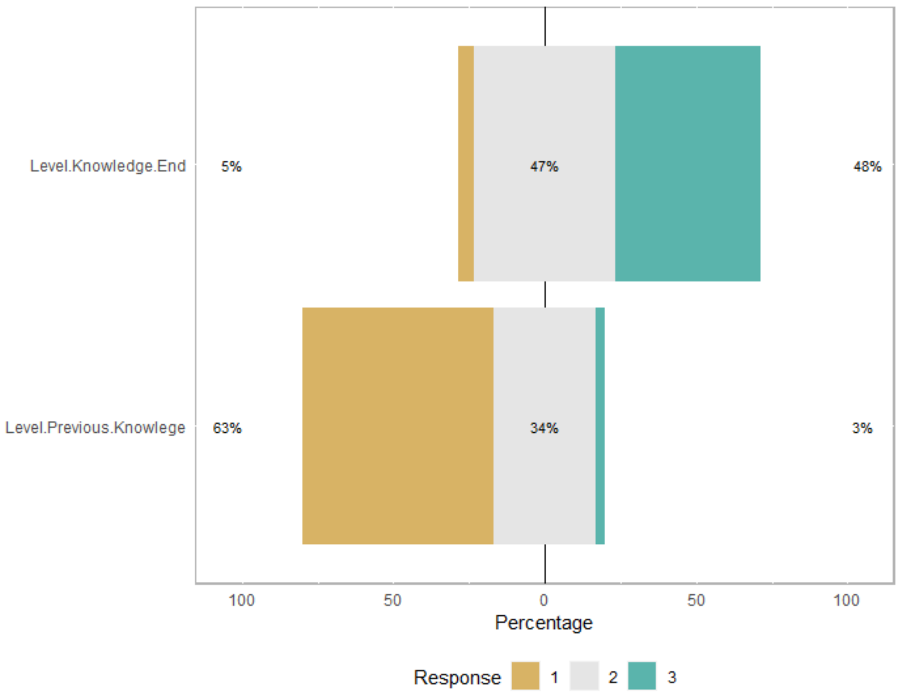

Figure 4: Students' perceptions of their learning.

Data Related to the Completion Rate, Grades and Course Evaluation

Table 5 presents data on course completion, grades, and student evaluation. The average grade on the final examination was 8.1 (SD = 2.35, on a 0–10 scale), while the course completion rate was 40%, corresponding to 345 of the 575 enrolled students. The second questionnaire, which assessed students' perceptions of the course, was completed only by those who successfully finished it. A total of 345 responses were received for this survey, while the initial survey (administered before the course) included responses from all 575 enrollees.

Overall, 55% of the respondents indicated that the course met their expectations, 41% reported that it exceeded their expectations, and only 3% felt it fell below expectations. These findings suggest a high level of satisfaction among those who completed the course. Although no inferential analyses were conducted, the relatively small number of respondents and the descriptive focus of this study limited the statistical power to explore associations between course evaluation, exam performance, and completion. However, the available descriptive data suggest a positive alignment between student satisfaction and learning outcomes.

Table 5: Summary of Course Completion, Grades, and Evaluation Results

Measure	Description / Result
Enrolment	575 students enrolled in the course
Completed the course	345 students (40%)
Final exam (0-10 scale)	M= 8.1, SD = 2.35
Course Evaluation (n= 345)	
-Exceed expectations	41%
-Met expectations	55%
-Fell below expectations	3%

Data Related to Instructor´s Workload

Table 6 indicates that the development and delivery of the course consumed 146 hours.

Table 6: Instructor workload

Design Thinking Stage	Workload (in hours)	Total of hours
Empathise	• Creation of the questionnaire (2 h) • Analyse the data (4 h) • Creation of the personas (6h)	12 h
Ideate	• Analysis of the personas' needs (4h)	4 h
Define	• Choice of virtual learning environment (4h)	4h
Prototype	• Creation of the VLE (Google Classroom) (2h) • Creation of the course website (4h) • Creation of the video-lectures (56 h)	62 h
Test	• Delivery of the course (52 h) • Creation of the questionnaire (2h) • Creation of the exam (6h) • Evaluation of the results (4h)	64 h

Qualitative Results

The qualitative data analysis revealed four recurring themes (RTs). Representative student quotations are provided for each theme to exemplify the findings.

RT1: **Well-crafted short videos enhanced interest and enjoyment**

The students expressed their enjoyment in watching the videos, noting their clarity and conciseness. One participant remarked: "*Short and quick videos are more attractive and less boring*." Another learner added: "*Excellent and short classes, which make it easier to include the lessons in our daily routine. Thank you very much*."

RT2: **Well-designed problem sets met student expectations**

Numerous students affirmed that the proposed problems and challenges resonated with their expectations. These exercises facilitated their understanding of computational reasoning and coding. A student pointed out: "*The course was very well designed, with great planning and excellent lessons/explanations. Very good for those starting with R — everything was well explained, and the practical activities were excellent*." Another participant observed: "*The learning method was of a high standard because, in a simple way, I was able to learn concepts that I had difficulty within other courses. It exceeded my expectations.*"

RT3: **Problem-based learning approach amplified learning experience**

Students attested to their engagement with the presented problems, relishing the "learning-by-doing" approach. They communicated their interest in these problems and described the experience of solving them as enjoyable. One learner said: "*Excellent course. Including short codes in the final test made understanding even better. Thank you very much*!" Another participant reflected: "*I have taken several R courses, and all of them taught me how to access data in tables (importing a dataset with health data and accessing rows, columns, summary values…). What I really needed was to play with programming in R — and your course allowed me to do that!*" A student noted: "*The video lessons were very useful, and I loved practicing with the exercises. I also found it interesting that there were no due dates for assignments, which was something that worried me in other courses and kept me from enjoying the classes, as I always wanted to get a better grade within the deadline*." Another learner commented: "*The classes were great, and the exercises were excellent for practicing the covered topics.*" One participant added: "The exercises and examples made the course much more fun and engaging. Thank you very much for the opportunity."

RT4**: Empathetic instructor behaviour bolstered student motivation to learn**

Students reported their appreciation for the instructor's dedication in addressing their questions on the discussion forum. They also valued the availability of video lectures on the course website after course completion, which enabled later review. The accessibility of all course materials from the start of the term allowed students to learn at their own pace. Additionally, learners praised the instructor's prompt and comprehensive feedback.

One participant remarked: "*I loved the way the instructor communicated with the students. He spoke simply, using easy-to-understand examples.*"

Another learner added: "*I would like to congratulate the instructor because the course was presented clearly and in a very didactic way*."

A student emphasised: *"I just want to highlight that the instructor has incredible teaching skills — his classes were excellent. I would like to congratulate the instructor, the institution, and everyone involved for offering such a high-quality course and teaching materials to the broader community."*

DISCUSSION

Returning to the first research question (How does the use of Design Thinking–driven personas in the design of an undergraduate STEM MOOC influence the alignment between course content and student interests?), RT1 (Well-crafted short videos enhanced interest and enjoyment) indicated that our decision to create concise videos based on persona analysis was highly effective. Moreover, the quantitative data (Figure 3) underscored that students acknowledged the superior quality of the video lectures. Additionally, RT2 (Well-designed problem sets met student expectations) indicated that the use of personas facilitated a precise understanding of students' interests, enabling a meaningful course. The quantitative data (Table 5) further showed that, for most students, the course either met or exceeded expectations.

This led us to our first conclusion, that the use of personas enhanced the design and delivery of a course aligned with students' interests. This discovery resonates with findings from other scholars (Arantes do Amaral et al., 2022; Kelle et al., 2015), who highlight the utility of personas in online course design. Similarly, it aligns with the work of Mor et al. (2015), emphasising the importance of MOOCs centred on students' needs.

Turning to our second research question (How does the application of a problem-based learning approach influence course completion rates in a MOOC?), RT3 (Problem-based learning approach amplified learning experience) highlighted that students appreciated the hands-on learning experience, expressing enthusiasm for the "learning by doing" approach. The data (Figure 3) also indicated that students encountered little difficulty in tackling the problems presented. Additionally, students' final examination grades (Table 5) demonstrated the effective application of the concepts learned. Data from Figure 4 further revealed that students perceived a clear enhancement in their learning throughout the course.

This led us to our second conclusion, namely that the problem-based learning approach enhanced students' engagement and learning experience. This conclusion aligns with the observations of other researchers (Daalhuizen & Schoormans, 2018), who emphasise the benefits of experiential learning approaches in MOOCs.

Addressing our third research question (How do students perceive their engagement and the challenges of participating in a MOOC that integrates Design Thinking and Problem-Based Learning?) and RT4 (Empathetic instructor behaviour bolstered student motivation to learn), students perceived the strategy of promptly and thoughtfully addressing their queries as highly effective.

This led us to our third and final conclusion, that demonstrating empathy, thoughtfulness, and providing swift feedback served as motivators for the students. This conclusion aligns with the work of Bakki et al. (2015), who emphasise the importance of engagement and motivation in MOOCs. It also resonates with the observations of Barrett (2005) and Hsbollah & Hassan (2022), who note that intriguing problems heighten students' interest in learning.

CONCLUSION

What insights can be gained from this experience?

This study demonstrates that integrating Design Thinking (DT) and Problem-Based Learning (PBL) in a MOOC context can effectively support high course completion rates and students' self-reported satisfaction with course quality and engagement. The use of personas was essential in designing targeted video content and problem sets that aligned with survey data on student interests.

The problem-based learning approach, combined with concise and engaging lectures, contributed to a learning experience that students found meaningful. Students responded positively to the hands-on nature of the course, demonstrating high motivation and success in applying the concepts learned.

In sum, our findings suggest that the synergistic application of DT and PBL creates a pathway towards alignment between course design and learner needs while also helping to support student motivation, engagement, and perseverance in online learning environments. While this approach demands a significant investment of time and effort from instructors, the educational benefits for learners are substantial and promising for future MOOC development.

Nevertheless, the 146 hours dedicated to course design and delivery highlight the importance of developing strategies to reduce instructor workload and enhance scalability. Institutional support—through teaching assistance, reusable learning materials, and AI-powered tools—could help sustain the quality of this pedagogical model while making its large-scale implementation more feasible.

It is also important to acknowledge that this course was developed and delivered within the specific institutional context of the Federal University of São Paulo (Unifesp), where professors voluntarily offer free extension courses as part of their academic service, career progression, and research activities. This incentive structure may differ from institutions where teaching loads, financial constraints, or incentive systems limit instructors' ability to dedicate similar levels of time and effort. Therefore, while the pedagogical model presented here is transferable, its successful replication in other contexts may depend on the availability of institutional support, incentive alignment, and workload policies that recognise and value the instructional commitment required for such initiatives.

In summary, although the course has not yet influenced institutional policy or decision-making within Unifesp, it represents an important component of the university's broader Massive Open Virtual Education Project, which aims to expand access to free, high-quality MOOCs. This innovative model of large-scale, open extension education has gained international recognition through the MIT AI + Open Education Initiative, funded by the Hewlett Foundation, where we published an article and participated in the "Updates from the Field" event — a global forum that brought together educators and researchers from multiple countries. Building on this recognition, we subsequently organised a large-scale course in collaboration with the Universidad de Chimborazo (Ecuador), which brought together students from Brazil and Ecuador, further extending the reach of this initiative and fostering international collaboration in open education.

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APPENDIX A – SUMMARY OF THE FIRST QUESTIONNAIRE

The questionnaire consisted of 15 closed-ended questions and one open-ended question. The closed-ended items aimed to obtain demographic, educational, and motivational data about participants, while the open-ended item invited qualitative comments or suggestions. A summary of all items is presented below.

Question No.	Topic / Purpose	Example or Description	Response Type
1	Informed consent	Confirmation of voluntary participation and ethical terms.	Single choice ('Ciente')
2	Age	Participant's age (numerical).	Open numeric field
3	Gender	Male / Female.	Multiple choice
4	State of residence	State within Brazil (27 options) or 'Other country.'	Multiple choice
5	Previous participation in similar course	"Did you take the previous Data Science course?"	Multiple choice
6	Intention to complete the course	"Do you plan to complete the course?"	Multiple choice (Yes / Maybe / No)
7	Familiarity with R programming	"How would you describe your knowledge of R?"	5-point scale (None → Expert)
8	Educational background	"What is your highest educational level?"	Multiple choice (Elementary → Postdoc)
9	Type of higher education institution	"Where did you complete your degree?"	Multiple choice (Federal / State / Private / Other)
10	Field of occupation	"What is your professional field?" (STEM, Health, Humanities, etc.)	Multiple choice
11	Work experience	"How many years of professional experience do you have?"	Multiple choice (None → 15+ years)
12	Motivation for	Reasons such as curiosity,	5-point Likert

	enrolling	professional need, certification, or recommendation.	scale
13	Learning aspirations	Goals such as applying knowledge in work/research or skill development.	5-point Likert scale
14	Learning conditions	Availability of time, study environment, equipment, and internet.	5-point Likert scale
15	External challenges	Workload, sharing computer, family duties, or stress affecting performance.	5-point Likert scale
	Open-ended item	"Do you have any questions, comments, or suggestions?"	Open text field

APPENDIX B – POST-COURSE QUESTIONNAIRE

The following items were used to assess students' perceptions of the **difficulty** and **quality** of the course materials, as well as their overall experience in the course.

Participants were asked to respond to each closed-ended question using a **three-point Likert scale**, where:
1 = Low **2 = Medium** **3 = High**

Closed-Ended Questions

1. In relation to the **video lessons** of the course, how would you rate their **level of difficulty**?
☐ 1 – Low difficulty
☐ 2 – Medium difficulty
☐ 3 – High difficulty

2. In relation to the **problems** proposed during the course, how would you rate their **level of difficulty**?
☐ 1 – Low difficulty
☐ 2 – Medium difficulty
☐ 3 – High difficulty

3. How would you rate the **overall level of quality** of the **video lessons**?
☐ 1 – Low quality
☐ 2 – Medium quality
☐ 3 – High quality

Open-Ended Question

4. Please share your thoughts about the **structure of the course**, your **learning experience**, and your **overall evaluation** of the course.

APPENDIX C – SUMMARY OF PROGRAMMING QUESTIONS (Q1–Q10)

The following questions were part of the final assessment for the *Introduction to Programming with R* course. They evaluate basic programming logic, control structures, and data handling in R.

Q1. *Understanding a countdown function*
Students interpret a function that prints numbers from 10 down to 0 using a while loop.

Q2. *Conditional logic (if–else)*
Students complete missing words ("XXX", "YYY") in an if–else statement that checks whether a number is even or odd.

Q3. *For loop and multiplication tables*
Students analyze a for loop that prints the multiplication table of a user-input number (from 1 to 10).

Q4. *Nested conditionals with numerical classification*
Students identify the correct logical flow of a nested if–else structure determining whether a number is positive, zero, or negative.

Q5. *Function with arithmetic operations*
Students evaluate a simple function that returns the result of subtracting twice a constant from an input value.

Q6. *Iterating through a vector with a loop*
Students analyze a function that counts the number of even elements in a given numeric vector.

Q7. *Application of the previous function*
Students determine the output when applying the even-counting function to a specific numeric vector.

Q8. *Matrix creation using dim()*
Students interpret how assigning dimensions to a numeric vector creates a 4×2 matrix.

Q9. *Row binding vectors with rbind()*
Students identify that combining two vectors using rbind() produces a matrix by stacking them as rows.

Q10. *List structures in R*
Students interpret a list object containing names, ages, city, and gender, and determine how to extract a specific element from the list.

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