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The Teaching–Research–Extension Triad in Action: Curriculum-based Extension in a Software Engineering Program

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Abstract

This paper presents a longitudinal case study investigating how curriculum-based extension can operationalize the teaching–research–extension triad in a Fundamentals of Software Engineering course within a Brazilian undergraduate program. The study has two main objectives: (1) to document how teaching, research, and extension were organically integrated across three consecutive semesters, and (2) to analyze the meanings undergraduate students attributed to this experience. The extension activity was conducted in partnership with a public high school, where undergraduate student teams developed Augmented Reality content for Biology classes using a platform under active development as a research project. They were required to apply software development life cycle concepts to create 3D models and quizzes aligned with the school's curriculum, thereby experiencing requirements gathering, iterative development, and external stakeholder validation. The research design follows a dual-loop structure: within each semester, teams progressed through requirements, development, partial review, final delivery, evaluation, and final report stages; between semesters, findings from qualitative analysis and pedagogical review informed refinements to the instructional design and technical support for the subsequent iteration. Quantitative data comprised assignment grades, scene adoption rates, and question approval rates. Qualitative data were collected through a fixed open-ended instrument and analyzed using a constructivist Grounded Theory approach, encompassing open, axial, and selective coding stages, with co-author review to support analytical rigor. Results show a progressive improvement in material quality and adoption rates across semesters, driven by the reduction of task ambiguity and the progressive increase in the weight of partial evaluations. Qualitatively, undergraduate student perception shifted from technical surprise to critical reflection and, ultimately, to recognition of the activity as an authentic simulation of professional software development practice. The findings suggest that anchoring extension in a developing research artifact enables a sustainable and replicable framework that integrates the teaching–research–extension triad, develops complex engineering competencies, and generates socially relevant outputs for the partner community.

Keywords: *Curriculum-Based Extension; Software Engineering Education; Augmented Reality; 3D Modeling; Teaching–Research–Extension Triad.*

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1 Introduction

University extension is conceived as an educational, cultural, and scientific process that articulates teaching and research in an inseparable manner, aiming at a transformative interaction between the university and society (Ribeiro et al., 2018; Steigleder et al., 2019). Although this principle of inseparability is consolidated in Article 207 of the 1988 Federal Constitution and reinforced by national guidelines, such as Resolution CNE/CES No. 07/2018, its full execution still faces significant obstacles (Faria & Almeida, 2025; Machado et al., 2024).

In practice, extension often occupies a position of lower prestige within the academic triad compared to teaching and research, being frequently reduced to isolated actions or the mere provision of services, thus distancing itself from an effective curricular integration that promotes academic, professional, and civic training truly committed to social reality (Oliveira et al., 2020).

The implementation of the curriculum-based of university extension in undergraduate programs, especially in the fields of science and technology, has been described as a complex process that requires structural, pedagogical, and cultural changes within higher education institutions (Ribeiro et al., 2018; Steigleder et al., 2019). Studies indicate that one of the main challenges is to transform extension from isolated actions into systematic practices integrated into the program's pedagogical project (PPP) (in Portuguese "Projeto Pedagógico do Curso"), ensuring the inseparability of teaching, research, and extension without overcommitting the students' and faculty's workload (Oliveira & Tosta, 2021). Furthermore, the need for alignment with the National Curriculum Guidelines (in Portuguese "Diretrizes Curriculares Nacionais") and university extension policies demands a revision of syllabi, learning objectives, and assessment methods, which often encounters institutional resistance and coordination difficulties between departments (Gonçalves et al., 2023; Ribeiro et al., 2018).

When dealing with projects involving the use of digital technologies and technological fields, additional challenges emerge regarding infrastructure and the articulation of expectations between the university and society (Gonçalves et al., 2023; Lima et al., 2025). The literature highlights that, although such projects increase student engagement and promote meaningful learning in engineering education, their implementation requires careful planning and systematic monitoring instruments to effectively consolidate as sustainable practices (Lima et al., 2025).

The present work reports three semesters of a real-world project in partnership with the Gertrud Aichinger Basic Education School, which serves only high school students in the city of Ibirama. It applies a research project addressing Augmented Reality (AR) in schools (Vanzuita et al., 2025) within the "Fundamentals of Software Engineering" (FSE) course during the first semester of the Bachelor of Software Engineering (BSE) program at University of Santa Catarina State (UDESC). The objective of this work is to present this case study of curriculum-based extension, articulated with teaching (an assignment within the course) and research (utilizing EducaAR, an AR platform being developed as a research project), and to analyze the contributions to the professional profile of the Software Engineering (SE) graduate. Therefore, two research questions are to be answered in the conclusion: **RQ1.** How does the experience integrate teaching, research, and extension in practice? and **RQ2.** What meanings do undergraduate students attribute to the experience?

Despite the growing body of literature on the legal and administrative challenges of curricularizing extension in Brazil (Machado et al., 2024; Oliveira et al., 2025; Souza et al., 2018; Vieira & Lanser, 2025), there remains a significant gap regarding the pedagogical operationalization of the teaching-research-extension triad in technical courses. Most existing studies describe short-term interventions or focus on general digital literacy. There is a lack of longitudinal case studies that demonstrate how a consolidated research artifact can serve as a scaffold for extension activities, ensuring that undergraduate students develop complex engineering competencies rather than performing generic community service. This paper addresses this gap by detailing a three-semester cycle where research outputs drive extension actions, providing a replicable model for specialized engineering education.

The remainder of this paper is organized as follows: Section 2 presents the background, discussing the teaching-research-extension triad and the challenges of curriculum-based extension in engineering fields. Section 3 describes the methodology, outlining the research design, the institutional context, the AR platform, and the pedagogical organization of the activity. Section 4 focuses on the pedagogical design and quantitative results, detailing the adjustments and evaluations across the three semesters. Section 5 presents the application of the produced materials in the school context, illustrating how high school students interacted with the AR scenes. Section 6 details the qualitative analysis of undergraduate student perceptions, examining how their insights and conceptual awareness evolved across the semester. Finally, Section 7 concludes the paper by addressing the research questions and presenting limitations and future work.

2 Background

This section establishes the theoretical foundations for the study, first discussing the institutional context of the teaching-research-extension triad in Brazil, and subsequently analyzing the challenges and practices of curriculum-based extension specifically within engineering and technological education.

2.1 Extension in Higher Education: The Brazilian Context

The historical and institutional consolidation of university extension in Brazil has been strongly shaped by the action of national representative forums, particularly the Forum of Pro-Rectors of Extension (FORPROEX) and the National Forum of Extension and Community Action of Community Institutions (FOREXT). These forums played a central role in systematizing principles, qualifying practices, and consolidating extension as an academic function inseparable from teaching and research (Faria & Almeida, 2025). The creation of FORPROEX in 1980 was instrumental in the constitutional recognition of the teaching–research–extension triad and in the formulation of the National Extension Plan, which established guidelines and goals for the institutionalization of extension (Steigleder et al., 2019). In this trajectory, the articulation among forums culminated in the approval of Resolution CNE/CES No. 07/2018, which represents a regulatory milestone for the curriculum-based extension in Brazilian higher education.

Within this regulatory framework, the curriculum-based extension is defined as the mandatory and organic integration of extension programs and projects into undergraduate curricula, with the objective of operationalizing, throughout the educational process, the inseparability between teaching, research, and extension (Vieira & Lanser, 2025). As established by Strategy 12.7 of the National Education Plan (2014–2024), this integration requires that at least 10% of the total curricular workload be allocated to extension activities (Faria & Almeida, 2025). Although national guidelines define minimum parameters, institutions retain autonomy to adopt different implementation models, provided that extension is incorporated into the pedagogical project of the program and effectively contributes to student learning (Oliveira et al., 2020).

Beyond its legal dimension, the curriculum-based extension poses pedagogical and epistemological challenges, particularly the risk of being reduced to formal or additive practices that reproduce fragmented, welfare-based, or utility-driven conceptions of university–society relations (Azevedo et al., 2025; Hernandez & Machado, 2025). In this sense, several studies emphasize that the effectiveness of curriculum-based depends on structural and curricular reorganization, as well as on a critical redefinition of extension itself, moving away from isolated actions toward dialogic, continuous, and socially referenced practices (Faria & Almeida, 2025; Hernandez & Machado, 2025; Oliveira et al., 2020).

When conceived from this critical perspective, university extension assumes a formative role that articulates teaching and research through engagement with real social demands, fostering reflective learning, civic responsibility, and professional development (Azevedo et al., 2025; Faria & Almeida, 2025). Thus, curriculum-based extension can function not merely as a compliance mechanism, but as a pedagogical strategy capable of strengthening the university's social commitment and of reconfiguring the educational experience in higher education (Machado et al., 2024).

2.2 Curriculum-Based Extension in Engineering and Technological Fields

Empirical experiences reported in Engineering and Computing programs demonstrate that the insertion of extension projects commonly occurs through project-based curricular units, integrative modules, or capstone-like experiences grounded in real-world problems (Cruz et al., 2024; Melo et al., 2023; Oliari et al., 2021; Santos et al., 2020). These initiatives typically involve partnerships with schools, public institutions, non-governmental organizations, or local communities, enabling undergraduate students to apply technical knowledge to authentic socio-technical challenges. Studies emphasize that such experiences foster greater student engagement, promote interdisciplinary collaboration, and contribute to the development of ethical, social, and communicative competencies, which are often underrepresented in traditional, content-centered curricula.

This approach allows students to progressively deepen technical complexity while maintaining a sustained relationship with real contexts and stakeholders. In Computing and SE programs, extension projects frequently address digital inclusion, educational technologies, and community-based software solutions, reinforcing the alignment between curricular content, professional practice, and social impact (Bordin, 2023; Melo et al., 2023).

From a pedagogical standpoint, curriculum-based extension is strongly associated with active learning methodologies. The literature establishes clear connections with project-based learning (PBL), problem-based learning, and experiential learning, as extension activities inherently require students to investigate problems, propose solutions, implement artifacts, and reflect on outcomes (Gonçalves et al., 2023). These methodologies reposition students as active agents in the learning process and redefine the instructor's role as that of a mediator or facilitator, consistent with contemporary approaches in Engineering education.

Furthermore, the integration of extension into the curriculum contributes directly to competency-based education models. By engaging in extension projects, students mobilize not only technical knowledge, but also transversal competencies such as teamwork, communication, autonomy, critical thinking, and social responsibility (Oliveira et al., 2025). The reviewed studies argue that competency development is enhanced when learning objectives, assessment criteria, and extension activities are explicitly aligned, allowing competencies to be observed and evaluated in authentic contexts rather than through decontextualized examinations (Cruz et al., 2024).

In summary, experiences in Engineering and Technological fields indicate that curriculum-based extension functions as a convergent space where active methodologies and competency-oriented education intersect (Chans et al., 2024). When systematically planned and institutionally supported, extension projects enrich curricular structures, strengthen the relationship between university and society, and contribute to the holistic formation of future engineers and computing professionals, in line with contemporary educational and societal expectation (Schuh et al., 2024; Souza et al., 2018).

3 Methodology

3.1 Research Design

This work adopts a longitudinal case study design (Saldaña, 2003; Yin, 2015), spanning three consecutive semesters (2024-1, 2024-2, and 2025-1), to investigate the implementation of curriculum-based extension in the FSE course. In line with the framework of Yin (2015), longitudinality here refers to the repeated observation of the same phenomenon across successive iterations, rather than the tracking of the same individual participants. Looking at multiple groups that go through the same structure at different moments is a legitimate way to capture the density of a process (Saldaña, 2003). Although a new group of first-semester students entered the course each term, the core focus of our study never changed. Our unit of analysis remained the curricular extension activity itself: specifically, its instructional design, grading structure, community partnership, and the research platform supporting it. By keeping this focus steady throughout the semesters, we were able to run systematic comparisons and continually refine our teaching methods, capturing the true essence of longitudinal case study research in education.

Case study was chosen as the research strategy because it allows for an in-depth, contextualized examination of a real-world phenomenon (Crowe et al., 2011), i.e., the operationalization of the teaching-research-extension triad, within its natural institutional setting. The longitudinal dimension enables the observation of how pedagogical decisions, undergraduate student perceptions, and outcome quality evolved iteratively over time, which would not be captured by a single-semester snapshot. Data were collected from multiple sources across each semester: assignment evaluation scores, adoption rates of the material produced by the partner teacher, and students' written final reports. The convergence of these sources supports the internal validity of the findings.

3.2 Institutional and Participant Context

The study was conducted within the BSE program at UDESC. The FSE course is a four-credit, 72-contact-hour course offered in the first semester of the program, of which one credit (18 hours) is allocated to extension activities, in accordance with the program's revised Pedagogical Project (PPP). In BSE, extension credits were incorporated into the workload of several courses, in addition to four credits that undergraduate students must fulfil through voluntary participation in Extension Programs and Projects. Table 1 summarizes the participant and contextual characteristics across the three semesters.

Table 1: Participant and contextual characteristics

Semester	No. of Teams	Max. Students	Biology Topic	High School Grade Level
2024-1	15	45	Cell organelles	1st year
2024-2	15	45	Biological tissues	1st year
2025-1	10	40	Biogeochemical cycles	3rd year

All participants were first-semester undergraduate students enrolled in the BSE program, with no prior coursework in 3D modeling. The external partner was a public high school located in the same city as the university, represented primarily by a Biology teacher responsible for the Science Laboratory. This teacher participated actively in all three semesters, defining the biological content to be addressed, conducting interviews with student teams during the requirements phase, performing pedagogical evaluations of the submitted materials, and providing feedback during the partial assessment stage.

3.3 Research Project of AR Platform

One of the authors of this paper is the coordinator of a research project that develops a web-based platform to be used as a Learning Management System (LMS), called EducaAR, in which content is represented through 3D models that can be visualized and interacted with (e.g., zooming and rotating). These interactions occur when users point their mobile phones at images in a textbook associated with the models, known as markers. This functionality characterizes the use of AR. The combination of the marker and the 3D model is referred to as an AR scene. In addition, a multiple-choice questionnaire can be answered after interaction. All details of the project, the platform, and the evaluation of the first experiment conducted with a high school class are available in Vahldick et al., (2023) and Vanzuita et al. (2025).

When the project was originally written in 2021, during a period in which full-time high school education was being planned, the initial pedagogical proposal was to offer college students extracurricular courses on free 3D modelling tools. Teachers could then assign didactic activities in which they would model artifacts related to the content being taught or about to be taught. In this way, they would need to study the subject matter to understand what should be modelled, fostering more meaningful learning due to the closer relationship between theoretical content and practical development.

Although the full-time high school initiative was later abandoned, the project received funding in 2022, and the development of the platform began. As a result, an AR platform was available; however, a gap remained regarding who would be responsible for developing the AR scenes. At the same time, the University required the undergraduate programs to revise their PPPs to account for the accreditation of extension activities.

3.4 Pedagogical Organization of the Curriculum-Based Extension Activity

In this context, in the first semester of 2024, the research project coordinator taught the course FSE. EducaAR was presented to a group of teachers from the Gertrud Aichinger Basic Education School, and the Biology teachers agreed to participate in the experiment. One of them is responsible for activities in the Science Laboratory. Together, the team organized how the extension activity would be conducted. This laboratory teacher was present during the first semester in which the extension activity was implemented. This paper reports on three semesters of this extension activity.

In the course, undergraduate students are introduced to the concept of a basic software development life cycle (Pressman & Maxim, 2016). The objective of the extension activity is for students, organized into teams, to experience the software development life cycle and to recognize the importance of being open and willing to learn new skills, an essential competence for professionals in the technology field, since they are required to independently learn 3D modelling tools.

The course instructor informs the Biology teacher of the number of teams, and she defines the high school grade level, the topic to be addressed, the textbook to be used, and divides the content according to the number of teams. The assignment prompt is already divided by specific topic, including the book reference and the related page numbers. The extension activity is organized as follows: in the first meeting, the content assigned to each team is randomly selected, the physical books are brought in so they can take photos of the markers and the page related to the activity, and the Biology teacher visits the University to be interviewed. Each team's task is to develop 3D models corresponding to the textbook figures related to their assigned content, as well as to create questions and multiple-choice answers. Undergraduate students are consistently reminded that the use of Large Language Model (LLM) tools is not appropriate, as the answers must be directly related to the figure used as the AR marker.

The information provided by the assignment description and the interview constitutes the first phase of the software development life cycle: the requirements phase. Several instructional sessions on development are offered (covering analysis, design, implementation, and testing), during which each team, in addition to studying the subject matter, must learn modelling tools and develop communication and documentation practices within the team. During this period, undergraduate students already have access to EducaAR with a developer profile. The platform supports four different user profiles (Vanzuita et al., 2025). Utilizing the developer profile, academics construct scenes by uploading markers and 3D models, and formulating the associated quizzes.

At the end of these stages, teams present a first version of their work to the Biology teacher, who may intervene with suggestions. The teams then carry out another development iteration and submit the final version. After submission, a technical evaluation is conducted by the FSE instructor, and a pedagogical evaluation is performed by the Biology teacher. Before receiving their grades, the teams complete an anonymous form called the Final Report, consisting of five open-ended questions (Appendix A).

Figure 1 presents a flowchart summarizing the research stages across the three semesters, illustrating both the within-semester activity cycle and the between-semester refinement loop. The research design is explained in detail in Section 4.

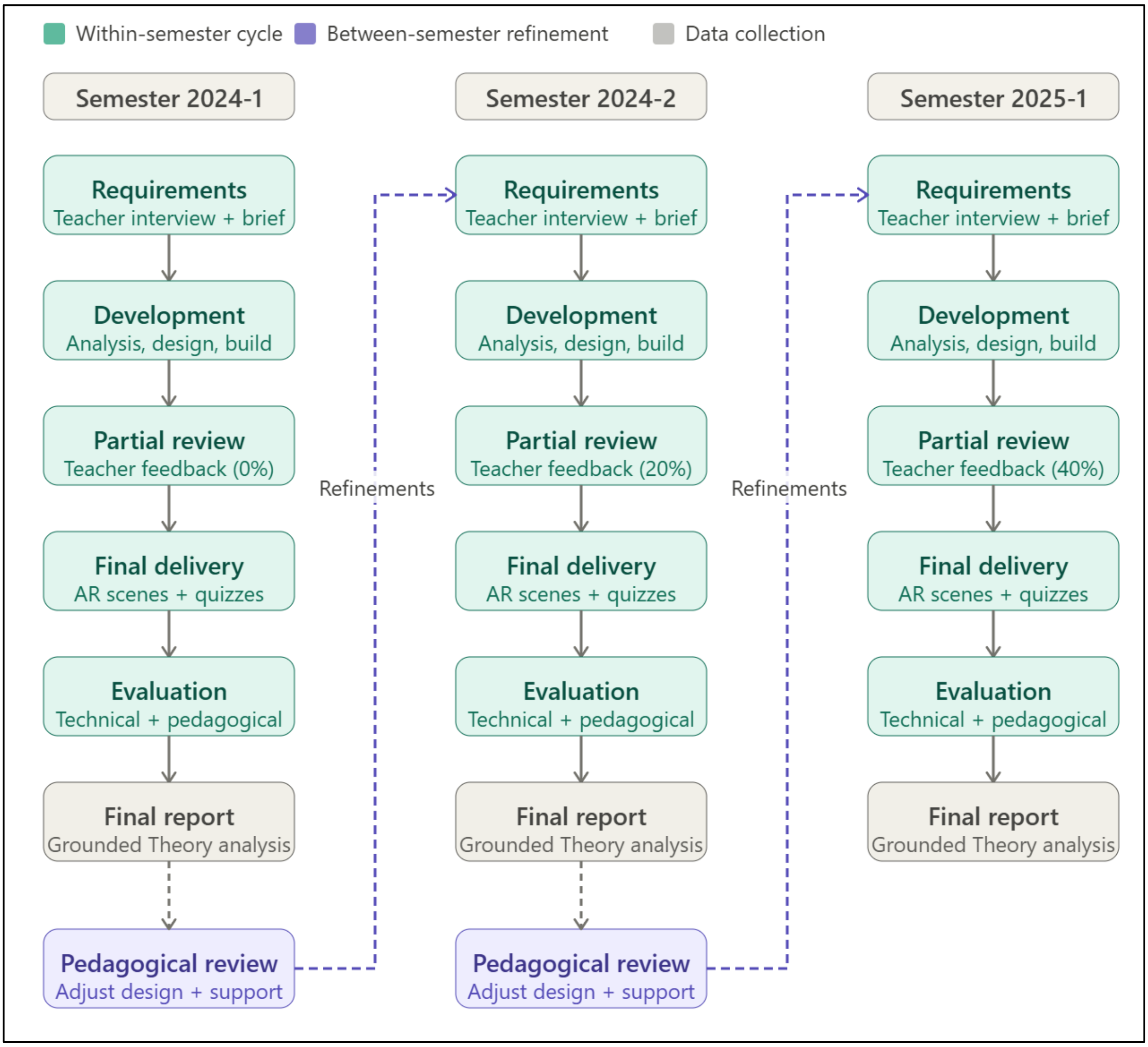

Figure 1: Research design flowchart

3.5 Data Collection and Analysis

Data were collected from two complementary sources. Quantitative data consisted of assignment grades assigned by the FSE instructor, adoption rates of the AR scenes by the Biology teacher, and question approval rates, recorded for each semester. Qualitative data were collected through the Final Report, an anonymous open-ended questionnaire completed by each team at the end of the extension activity, before receiving their grades. The instrument comprises five questions (Appendix A) addressing the tools used, the relationship between the activity and the software development life cycle, the effort and difficulties encountered, the modelling steps followed, and the perceived validity of the experience. The Final Report instrument remained unchanged across all three semesters, enabling longitudinal comparability of the qualitative data.

The qualitative analysis followed constructivist Grounded Theory approach (Charmaz, 2009), which acknowledges the researcher's situated perspective as an inherent and productive feature of the analytical process rather than a source of bias to be eliminated. Coding was conducted by the lead author, who is simultaneously the course instructor and the coordinator of the AR research project. This dual positioning provided deep contextual familiarity with the data while also requiring explicit reflexive awareness. To address this, the researcher maintained analytic memos throughout the coding process, documenting the reasoning behind code assignments and category boundaries, which served as an audit trail linking raw excerpts to final categories.

Open coding was performed through line-by-line reading of all Final Reports across the three semesters. Codes were generated close to the participants' own language, preserving their expressions and avoiding premature abstraction. All codes and their supporting excerpts were recorded in a structured spreadsheet, enabling traceability from the raw data to the resulting categories. In the axial coding stage, related open codes were grouped into analytical categories by identifying relationships among conditions, actions and interactions, and consequences. In the selective coding stage, categories were integrated around a central phenomenon that synthesizes the core experience described by the teams.

To compensate for single-coder analysis, two additional safeguards were adopted. First, the instrument's structure (five fixed open-ended questions systematically eliciting comparable content across all teams and semesters) constrained the interpretive space and reduced the risk of idiosyncratic readings. Second, the resulting categories and core phenomena were reviewed and discussed with the co-authors, who were not involved in the primary coding, providing an external check on the plausibility and faithfulness of the analytical outcomes. This procedure was applied independently to each semester's dataset, enabling longitudinal comparison of the emerging phenomena.

4 Pedagogical Design and Quantitative Results

The previous section presented the core of the applied methodology. This section will describe the topics covered, the changes made compared to the previous semester, and the results of the final assignment evaluation.

4.1 Semester 2024-1

The biology teachers used the textbook by Linhares et al. (2016a) specifically "Unit 3 - The Cell: Unit of Life", and Zamboni & Bezerra (2020) using "Unit 3 - The composition of living things". The subject was "Organelles and their structure" for tenth-grade students (First Year of High School). The class was divided into 15 teams of up to three undergraduate students each. Each team was required to develop three AR scenes with three questions each. However, if one of the 3D models featured animation, the requirement was reduced to only two AR scenes.

As a result of this work, 42 scenes were submitted, 24 (57.14%) of which were adopted by the teacher. While 126 questions were expected from these 42 scenes, the teachers approved 77 (61.11%) after evaluation. For the final implementation, 72 questions (3 questions * 24 scenes) were used. The average grade for the assignments was 7.39 (on a scale of 0 to 10) with a standard deviation of 1.85.

4.2 Semester 2024-2

Based on the experience from the first semester, it became clear that it was necessary to be more specific about which images from the textbook should be used as markers. The undergraduate students' primary motivation was learning and using a modeling tool rather than developing the instructional design, a task that would have been more tangible had they been enrolled in a teaching degree program.

For this reason, the teacher divided the subjects by pre-stipulating which images would serve as markers. Furthermore, drawing from the previous semester's experience, she was able to empirically establish complexity levels for the 3D models. Consequently, each topic could consist of one to three scenes; as requested by the teacher, some were required to include animation, with each scene containing three questions. The class structure remained at fifteen teams of up to three students. The textbook by Linhares et al. (2016a) was used again, focusing on Chapters 14 (Epithelial Tissue) and 15 (Connective Tissues). Thus, the subject was "Tissues" for first-year high school students. The textbook was provided in digital format (PDF).

In the previous semester, the partial evaluation with the teacher did not count toward the final grade. This semester, the partial evaluation accounted for 20% of the final assignment grade. An additional motivator for the undergraduate students was a shared news link showing that college students from the target school had used the materials produced the previous semester at a Science Fair[1].

This semester, a new feature was added to the EducaAR developer profile: users can now simulate the student profile on a mobile device to test 3D model performance and quality, as well as marker detection and quiz visualization. A developer manual was also provided, detailing all the features available for this profile.

As a result of this work, 20 scenes were submitted, 14 (70%) of which were adopted by the teacher. Out of these 20 scenes, 62 questions were produced (one team produced more than required); following the teacher's evaluation, 60 questions (96.8%) were approved. The average grade for the assignments was 8.14 (on a scale of 0 to 10) with a standard deviation of 2.3. While no teams received a maximum grade (10.0) last semester, six teams (40%) achieved that score this semester.

4.3 Semester 2025-1

The 3D models from the last semester exhibited higher quality than those from the previous semester. This improvement was justified by the reduction in the number of scenes each team had to produce, along with better instructional guidance for the task.

The specific changes compared to the previous semester were as follows:

- In the previous semester, some teams created 3D models with labels (as illustrated in Figure 2) and linked these identifiers to the quizzes. This strategy could result in the college students exploring the created models in greater depth. Consequently, this example was presented and suggested as a guideline for the teams to follow;
- Since the teacher aimed to improve model quality and quiz depth, she selected only five images and created two topics for each. This forced the teams to go beyond simple reproduction of the textbook figures. During her first interview visit, she used the whiteboard to list specific topics for undergraduate students to explore while designing their models and drafting questions;
- The textbook Linhares et al. (2016b) was used, focusing on Chapter 18 (Biogeochemical Cycles) for third-year high school students;
- The class was reorganized into 10 teams of 4 undergraduate students each. This change aimed for higher modeling quality, and the requirement was increased to four questions per AR scene;

[1] https://www.udesc.br/noticia/sistema_web_de_realidade_aumentada_desenvolvido_pela_udesc_alto_vale_e_destaque_em_mostra_de_ciencia.

- Since the exclusive use of Blender was observed in the previous semester (as will be detailed in the Final Reports evaluation), a manual was created with instructions on centering and model scaling, because these are some issues that students had raised during the previous partial assessment;
- The weight of the partial assessment increased to 40%. It was noted last semester that most teams worked ahead of the final deadline and aimed to finish modeling by the partial review. This change improved model quality, as it allowed the teacher to evaluate a nearly finished product, requiring only minor adjustments for the final version.

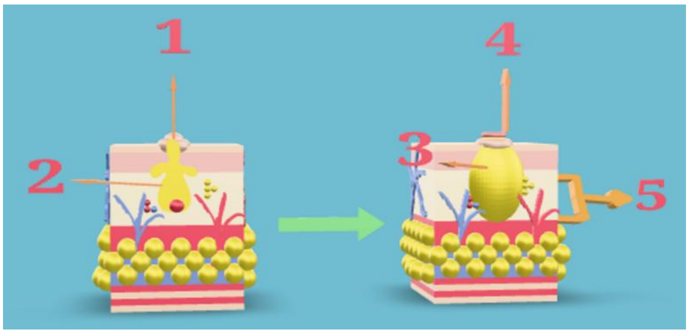

Figure 2: 3D model with labels

As a result of this work, 10 scenes were submitted, 9 (90%) of which were adopted by the teacher. While 40 questions were expected from these 10 scenes, the teachers approved 31 (77.5%) after evaluation. Naturally, this total was only for assessment purposes, as only 36 questions (4 questions * 9 scenes) were used. The average grade for the assignments was 8.19 (on a scale of 0 to 10) with a standard deviation of 1.79. In this semester, two teams (20%) achieved the maximum grade.

4.4 Summary of Quantitative Results

Table 2 presents the results data for each semester. The longitudinal observation of the three semesters highlights a clear maturation in the process of defining and delivering the assignment. This evolution is quantitatively evidenced by the data, which reveals a steady increase in the adoption rate of the materials produced and consistently high student performance as the instructional guidelines were refined.

Table 2: Descriptive Statistics Across Semesters

Metric	Semester 1	Semester 2	Semester 3
Scenes adopted	57.14%	70%	90%
Questions approved	61.11%	96.8%	77.5%
Partial assessment	0%	20%	40%
Average grade	7.39 (± 1.85)	8.14 (± 2.3)	8.19 (± 1.79)
Max grade (10.0)	0%	40%	20%

5 Application of The Produced Materials in School Context

The previous section highlighted the amount of material approved for the teacher to use in her classes. This section will briefly describe the experiences adopted in High School, demonstrating the use of the models created by the undergraduate students.

5.1 Materials Produced in 2024-1

The main motivation for this first experiment with students was to test the EducaAR platform and to challenge the teachers to define pedagogical strategies for applying AR in their classes. However, in order to test with the students, it was necessary to have some 3D models associated with the Biology subject, which motivated the discussion in this article.

The experiment took place between May and August 2024, applied to only one first-year high school class, with a sample size of 31 students (n = 31). They were divided into pairs, with only one team consisting of three members. Each team received a tablet provided by the school for exclusive use in Biology classes. However, due to the ease with which students could access their own devices, instead of scheduling a request to use the school's devices, students were allowed to use their own cell phones during these classes whenever the teacher permitted.

The first teaching strategy used consisted of making books available to the students; while the teacher explained the content using slides, she would pause the explanation on an image that the students had to locate using EducaAR, proceeding as soon as everyone had finished answering the related questions.

The strategy was changed because when students used their own devices, they tried to complete the activity as quickly as possible and ended up using them for activities unrelated to the class (e.g., accessing social networks). Therefore, she adopted another teaching strategy, where the material was divided into stations in the classroom, with the book pages related to the theme of each station already organized. The students were able to use their own devices, moving around and freely exploring the stations, where they could also scan the images and answer the questionnaires.

At the end of the experience, the students answered 12 items selected from the MAREEA instrument (Herpich et al., 2019), using a five-point Likert scale of agreement (from "strongly disagree" to "strongly agree"). This model evaluates their perception of AR's contributions to classroom experiences based on four factors: usability, engagement, motivation, and active learning.

From the analysis of the results of this instrument, the students concluded that the technology was functional. For them, the 3D models and the platform were the same. However, the general conclusion from this experience is that AR requires carefully structured teaching strategies to prevent distraction, given that students are in possession of their mobile devices. Further details can be found in Vanzuita et al. (2025).

5.2 Materials Produced in 2024-2

The teacher had planned to use the models again in the first-year classes in November 2024, but the school rescheduled its sports and social activities, compromising their implementation. Since 2025, the teacher did not return to teach these classes, and consequently, these models were ultimately not used in these classes.

5.3 Materials Produced in 2025-1

While the first experiment prioritized the functional validation of the EducaAR platform and revealed the importance of carefully structured teaching strategies for AR-based activities, this experiment shifted the focus to a pedagogical question: whether AR, when embedded in a deliberate instructional methodology, could contribute to the acquisition of conceptually demanding content. Biogeochemical cycles (covering carbon, water, nitrogen, and oxygen) were selected precisely because of their high level of abstraction: these are phenomena that students are expected to understand as dynamic, interconnected processes, yet are typically represented in textbooks through static diagrams. The use of AR was hypothesized to bridge this gap by enabling students to visualize and interact with 3D simulations of these processes, while the accompanying quizzes were designed to encourage them to actively seek and construct understanding of the content rather than passively receive it.

The experiment took place in August 2025 and was conducted with two third-year high school classes over four 45-minute sessions, with a total of 48 students (n = 48). In the first session, students completed a diagnostic assessment (pre-test); the second and third sessions were dedicated to studying the content using the platform; and the fourth session consisted of the post-test. Both tests comprised open-ended questions. Students were organized into groups of five or six members. Each group received a printed textbook and login to the EducaAR platform, and was allowed to use one group member's smartphone to access it.

Prior to the experiment, the EducaAR development team reviewed and adjusted all ten 3D models in response to the teacher's requests. Additionally, the teacher chose to limit each model to two quiz questions, prioritizing depth of engagement over breadth of content coverage.

The teacher adopted a Flipped Classroom methodology (Valente, 2014). At each topic, the teacher identified the relevant chapter in the textbook and directed students to locate the corresponding marker image to display the 3D scene. Since the quiz questions were tied to specific elements of the 3D model, students alternated between answering questions and re-examining the model, investigating it in greater depth while also consulting the text surrounding the marker image in the textbook.

As the platform allows the teacher to monitor each team's quiz performance in real time, students became curious about their own progress and expressed interest in tracking it themselves. The teacher responded by projecting the score page for each scene on the classroom board, making all teams' results visible simultaneously. This transparency had an unintended motivational effect: students became visibly more engaged in the activity, driven by the competitive dynamic of comparing scores across teams.

The teacher's assessment of the learning outcomes was encouraging: comparing the diagnostic and final evaluations, she observed that most students demonstrated a more detailed understanding of the biogeochemical cycles and were able to explain the underlying phenomena with greater scientific rigor.

A full analysis of the learning outcomes from this experiment, including pre- and post-test results, is currently under preparation and will be reported in a forthcoming publication.

6 Qualitative Analysis: Undergraduate Student Perceptions Across Semesters

While Section 4 documented the instructors' pedagogical decisions and quantitative outcomes across semesters, this section shifts the analytical lens to the undergraduate students' perspective, examining how they described and attributed meaning to the experience through the Final Reports. The analysis follows the open, axial, and selective coding stages described in Section 3.5, and is organized by semester, concluding with a joint discussion.

To conduct the Grounded Theory analysis on the Final Reports, it is necessary to establish a research question: "How do the teams describe their experience in creating 3D models and questions for the EducaAR platform, considering the tools used, the challenges faced, and the impacts on learning?”.

6.1 Final reports analysis

Following the analytical procedure described in Section 3.5, the final reports were examined through open, axial, and selective coding stages, and the findings are presented below by semester. Across all three semesters, a consistent baseline pattern emerged: no team entered the activity with prior 3D modeling experience, and all relied on online tutorials, trial and error, and task division as primary learning strategies. The per-semester analysis below focuses on what was qualitatively distinctive in each cycle beyond this shared baseline.

6.1.1 Semester 2024-1

Table 3 presents the open code generated from line-by-line reading of the 2024-1 Final Reports, anchored in the participants’ own expressions.

Table 3: Representative open codes and anchoring excerpts — Semester 2024-1

Excerpt (translated from Portuguese)	Open Code
we had no knowledge of tools nor familiarity with 3D modeling	zero prior knowledge
the biggest difficulty was learning to use the tools	tool learning curve
we learned to use the tools (even if through sheer frustration)	effortful but overcome
it was a cycle of trial and error until we managed to deliver the project	trial-and-error learning
we used a tool suggested by the instructor and another we found through research	mix of suggested and autonomous tool search
we divided the tasks, worked on them, and delivered	teamwork and task division
working with people we barely knew ends up simulating life in the job market	professional practice simulation
it was worth it	perceived formative value
from the start in requirements gathering to the end of the project, it was a real situation that would be put into practice	real-world situated learning

Relating these codes by their conditions, interactions, and consequences, axial coding yielded four analytical categories:

1. Initially unforeseen technical learning;
2. Challenges associated with a lack of prior knowledge;
3. Appropriation of the software development lifecycle;
4. Perception of formative value and authenticity of the activity.

The concluded central phenomenon was: “The experience of creating AR scenes for EducaAR is perceived as a situated learning process, marked by initial technical challenges, yet promoting autonomy, a practical understanding of the software development lifecycle, and the expansion of professional competencies”.

The learning of the tools is described as practical, exploratory, and based on trial and error, often associated with expressions of intense effort but also satisfaction upon overcoming difficulties.

The reported challenges are concentrated in three main axes:

- The learning curve of the tools, loss of models, format limitations, and adjustments for compatibility with the EducaAR platform;
- Understanding the Biology content required to correctly model structures and develop coherent questions;

- Coordination of teamwork, division of tasks, and scheduling conflicts.

Despite the difficulties, the predominant perception is that the activity was “worthwhile”. The teams reported impacts at different levels:

- Acquisition of new technical knowledge (3D modeling, formats, platforms);
- Practical understanding of the software development lifecycle stages;
- Development of transversal competencies, such as teamwork, autonomy, and problem-solving;
- Recognition of the activity’s relevance due to its real-world use in an educational context.

6.1.2 Semester 2024-2

The open coding stage produced the codes, listed in Table 4, from line-by-line reading of the Final Reports, each grounded in the teams' own wording.

Table 4: Representative open codes and anchoring excerpts — Semester 2024-2

Excerpt (translated from Portuguese)	Open Code
none of the members had any knowledge of modeling or animation	zero prior knowledge
it was necessary to watch many online classes, which generated a very steep learning curve	steep self-directed learning curve
we had quite some difficulty with the export part, as there were texture bugs which consumed more time than expected	technical and compatibility issues
we had to use another tool besides Vectary, Blender, because Vectary did not export correctly when animation was inserted	tool limitation driving tool switch
we received help from classmates who were not part of the group to manage to include the animation	peer collaborative learning
we felt that the activity required a greater focus on 3D modeling, which ended up deviating somewhat from the central proposal of the course	perceived curricular misalignment
the work could have been more balanced in relation to the course content	tension between modeling and SE content
the first real contact with a costumer, that costumer being the teacher	customer/stakeholder experience
it resembled market reality	professional practice simulation
it was a worthwhile but demanding activity	perceived formative value despite effort

Of particular note, codes expressing tension between modeling effort and core SE content were grouped under a critical reflective consequence, a qualitative shift absent from the previous semester. This relational analysis produced five categories:

1. Intensive and self-directed technical learning;
2. Technical challenges associated with tool and model complexity;
3. Progressive understanding of the software development lifecycle stages;
4. Experience working with a customer and external validation;
5. Tension between focus on 3D modeling and core SE content: that is, students perceive a mismatch between the effort required for 3D modeling and what they traditionally understand as the “core content” of SE.

These categories show that the 2024-2 semester was marked by greater technical complexity in both models and tool infrastructure, generating more critical reflections from the students.

The concluded central phenomenon was: “The creation of 3D models and questions for EducaAR is perceived as an intense formative experience, characterized by self-directed technical learning, significant challenges in modeling and tool integration, and the practical consolidation of the software development lifecycle stages, despite tensions regarding alignment with the course’s core content”.

The reports evidence the use of a wide variety of tools, with Blender standing out as the predominant tool and, in some cases, the use of AI tools for 3D model generation. The combined use of multiple tools is described as necessary to overcome the individual limitations of each environment. Last semester, the most cited 3D modeling tools were Vectary (9) and Blender (4). This semester presented an inversion: Blender (9) and Vectary (4). This shift occurred due to limitations regarding animation creation in Vectary.

The reported challenges are concentrated in three main axes:

- Difficulties with biological tissue texturing, file weight control, export bugs, incompatible animations, and AR scene rendering issues;
- The need to understand biological content to correctly represent structures and formulate coherent questions;
- The perception that the effort required for 3D modeling, in some cases, exceeded the expected focus of the SE course.

Despite the difficulties, most teams also consider the activity to have been “worthwhile”. The impacts on learning include:

- Acquisition of unprecedented technical competencies;
- Concrete experience with the software development lifecycle stages;
- Understanding the role of the client/stakeholder and external validation;
- Development of autonomy, resilience, and teamwork.

6.1.3 Semester 2025-1

Table 5 illustrates selected excerpts and their corresponding open codes as derived from the 2025-1 Final Reports.

Table 5: Representative open codes and anchoring excerpts — Semester 2025-1

Excerpt (translated from Portuguese)	Open Code
no team member had prior knowledge	zero prior knowledge
we learned from scratch	self-directed learning from zero
intensive use of YouTube tutorials	tutorial-based autonomous learning
initial difficulty with Blender	tool learning curve
organization as a success factor	organizational maturation
task allocation	structured task division
we learned something new	knowledge acquisition acknowledgment
it was a worthwhile but challenging activity	perceived formative value despite effort
working like a company	professional practice simulation
we used generative AI tools to initiate project development	instrumental use of AI as scaffolding
it was our first real contact with SE projects	situated SE entry point
we would like introductory sessions	request for reduced initial frustration
the organization is the main factor for project success	project management awareness
a constant feedback return from the customer, which helped the evolution of the modeling	customer feedback as quality driver
we felt quite some difficulty in modeling and keeping the project under 40MB	technical platform constraint

Axial coding then mapped relationships among these codes. Notably, no codes expressing tension between modeling and SE content emerged this semester, a meaningful absence marking a qualitative shift from 2024-2. Four categories were identified:

1. Initial acquisition of technical competencies and increased self-confidence (100% of the teams);
2. Project feasibility and the perception of working “like a company”, indicating organizational maturation;
3. Reduction of initial frustration and project progression through the instrumental use of Generative AI and repositories;
4. Explicit recognition of formative gains.

The concluded central phenomenon was: “The initiation of students into SE through a technically challenging extension project that promotes situated learning, teamwork organization, and early exposure to professional practices”.

The reported challenges are concentrated in two main axes:

- Steep learning curves for the tools, difficulties in creating and editing models from scratch, export issues (loss of textures, colors, or materials after export), and performance limitations (scenes that became too heavy and failed to render correctly on mobile devices);
- Initial difficulty in project planning, uncertainty regarding the division of responsibilities, and the need to learn teamwork simultaneously with technical learning.

No critical discourses regarding curricular misalignment emerged. Instead, the challenges are perceived as a natural part of a first contact with SE and projects of greater complexity.

The pedagogical validity of the activity is explicitly recognized by many of the teams, with recurring statements such as “we learned something new” and “it was a worthwhile experience”. Some teams suggest including introductory sessions or initial guides, not as a criticism of the proposal, but as a way to reduce initial frustration. The reported learning impacts include:

- Acquisition of unprecedented technical knowledge;
- Development of basic organization and teamwork skills;
- First concrete contact with SE projects;
- Increase self-confidence when facing technical challenges.

6.2 Summary of Qualitative Results

In this section, a comparison between the semesters and the teachers’ impressions is conducted. Initially, regarding the project’s perception, it shifts from “difficult” to “formative” across the semesters:

- 2024-1: Surprise at the complexity and a focus on the technical challenge;
- 2024-2: A more mature reflection on tools, organization, and learning;
- 2025-1: Perception of the project as a first real contact with SE.

Returning to the research question used to analyze the Final Reports the following points stand out:

- The teams describe their experience in creating 3D models and questions for the EducaAR platform as a challenging process, marked by the transition from initial technical uncertainty to the consolidation of professional competencies;
- Regarding the tools, their use evolved from a variety of software to the predominance of Blender, supported by Generative AI and repositories, driven by the need for animations and technical complexity;
- Regarding the challenges, the primary barriers included a steep modeling learning curve (as most participants had no prior knowledge), team time management, and the need to understand specific biological content to ensure pedagogical quality;
- Regarding the impacts on learning, students report significant gains in autonomy, teamwork, and a practical understanding of the software lifecycle, perceiving the activity as a valid simulation of market reality.

Table 6 illustrates the evolution of how pedagogical and technical inputs provided feedback for the process over the three semesters, resulting in the maturation of the project.

Table 6: Longitudinal Analysis of the Semesters

Dimension	2024-1 (Exploration)	2024-2 (Structuring)	2025-1 (Maturation)
Pedagogical Focus	Quantity of scenes and technical discovery	Marker specificity and scene complexity criteria	Creativity and depth in 3D models and questionnaires
Technical Support	Generic development instructions	Student profile simulator and developer manual	Manual covering common Blender issues
Assessment Incentive	Partial evaluation 0%	Partial evaluation 20%	Partial evaluation 40%
Core Result	**Learning by Trial and Error**	**Tension between Modeling and SE**	**Professional Practice Simulation**

Our findings contribute to the Informatics in Education literature by challenging the perception that extension in early undergraduate years must be limited to basic user support or digital inclusion. Contrary to models that dissociate extension from the core technical curriculum, this study confirms that anchoring extension in an active research project allows for the application of advanced SE concepts in a real-world context. This fills a critical gap identified in recent surveys: the need for sustainable frameworks that integrate the university's research agenda with community demands without overburdening the teaching staff or diluting the technical depth of the course.

A progressive increase was observed in the adoption rate of the scenes developed by the teams for use by the Biology teacher, rising from 57.14% in the 2024-1 semester to 90% in the 2025-1 semester. This growth can be attributed primarily to the reduction of task ambiguity: while in the first semester students reported difficulties related to instructional design and pedagogical requirements, the subsequent definition of pre-set markers and the provision of technical manuals allowed the focus to shift from troubleshooting basic export and compatibility issues to the pedagogical significance of the developed models.

Simultaneously, the students' perception of the project underwent a significant qualitative shift over time: in 2024-1, a feeling of surprise regarding the technical complexity predominated; in 2024-2, a tension emerged regarding the potential diversion of focus from core SE content due to the effort required by 3D modeling; and finally, in 2025-1, this tension was replaced by an understanding of the project as a realistic simulation of a software development environment, where learning new tools on demand is recognized as an essential professional competency. In this context, the decision to increase the weight of the partial evaluation, from 0% to 40% of the final grade, proved to be a critical success factor, as it prompted teams to conduct earlier design iterations. This enabled the Biology teacher to act effectively as stakeholder, requesting adjustments that raised the standard of final deliverables, as reflected in the stabilization of grade averages above 8.0. In summary, the extension activity evolved from being perceived as an isolated task to being understood as a situated software development process, where external validation and the social utility of the final product, provided meaning and purpose to the technical learning.

7 Conclusions

This study presented and analyzed, over three consecutive semesters, an experience of curriculum-based extension within the BSE program, articulating teaching, research, and extension through the development of AR scenes for the EducaAR platform in partnership with a basic education school. The longitudinal design allowed us to address the two proposed research questions. Regarding RQ1, the integration of the teaching–research–extension triad proved effective when the extension activity ceased to be peripheral and instead structured the core practices of the course: teaching materialized through the software development life cycle, research through the use and consolidation of a platform under continuous development, and extension through artifacts of real social utility validated and adopted by a partner teacher. Regarding RQ2, students progressively shifted from perceiving the activity as a surprising technical challenge to recognizing it as an authentic simulation of professional software development practice, in which learning new tools on demand and iterating on external feedback are understood as essential competencies.

The main contribution of this work lies in detailing a longitudinal model that organically couples the teaching–research–extension triad by using a developing research platform as a pedagogical scaffold. Distinct from broad surveys or isolated interventions, this approach ensures that early-undergraduate extension requires complex SE competencies rather than basic digital literacy, while sustaining a framework in which student outputs concurrently serve community needs and research objectives without overburdening faculty or diluting technical depth. From this trajectory, we derive structuring principles that can guide replication in other contexts: (1) the existence of a real social demand with concrete external validation; (2) the explicit alignment of the extension activity with the course's learning objectives; (3) assessment mechanisms that encourage iteration, reflection, and continuous improvement; and (4) the recognition that learning new tools and technologies is a constitutive part of professional training in technical fields.

However, this study has limitations that should be acknowledged. The analysis was conducted within a single institution and course, with a single external partner, which constrains the direct transferability of findings. More specifically, the model relies on a confluence of conditions that may not be readily available in other contexts: the existence of an ongoing research project producing a functional technological artifact; an instructor who simultaneously holds the roles of course coordinator and research project leader; and a partner teacher with sustained institutional commitment across multiple semesters. Replicating this model in courses where research and teaching are structurally decoupled, or in programs without an established community partnership, would require deliberate institutional arrangements that go beyond simple pedagogical adaptation. Furthermore, the activity's technical demands, particularly self-directed 3D modeling, are well-suited to a SE program, where learning new tools on demand is recognized professional competency. Transposing this model to non-technical or early-literacy contexts would require substantial redesign of both the extension task and the assessment structure. Additionally, the qualitative coding was led by the course instructor, whose dual role as researcher and practitioner, although addressed through reflexive safeguards, represents an inherent positionality.

Future work should investigate the replication of this model in other partners, and disciplines contexts, as well as examine the long-term impacts on student professional development.

It is worth noting that generative artificial intelligence was employed in this research as a supportive tool. Specifically, the Jenni AI[2] tool was used to assist in searching for and selecting scientific articles. Additionally, the Gemini[3] tool was used for text translation. ChatGPT[4] was utilized to assist in interpreting the analysis process using Grounded Theory. Finally, Claude[5] was used to support the responses to the reviewers. All texts and results generated by these tools were reviewed, edited, and validated by the authors, who assume full responsibility for the accuracy, veracity, and final content of the work.

All procedures performed in this study were following the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

[2] https://jenni.ai
[3] https://gemini.google.com
[4] https://chatgpt.com
[5] https://claude.ai/

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Appendix

A - Final Report

1. List the tools the team used to develop the work.
2. Explain how you understand the relationship between this work and the phases of the software development life cycle (requirements, analysis, design, development, and testing).
3. Comment on the effort required to develop the work (did the team members already have knowledge of the tools? Did they research the tools independently or use those suggested by the instructor?), as well as the difficulties encountered.
4. List the steps (relating them to the tools used) to model the AR scenes.
5. Justify your answer regarding the validity of the task. Was the work worthwhile? Did the team members learn something new? Do you believe this type of activity should be continued in the next semester?