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Adaptable Challenge-Based Learning in Computing Education

From preparatory activities to a novel framework for student self-regulation

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Abstract

The rapidly evolving landscape of the technology sector demands that Computer Science graduates possess not only technical proficiency but also transversal competencies, such as adaptability, critical thinking, and collaboration. While Active Learning strategies and specifically Challenge-Based Learning (CBL) have emerged as effective pedagogical responses to this need, their widespread adoption in engineering and computing curricula is hindered by several barriers. This dissertation addresses three of them: student readiness and motivation; necessary resources and scalability; and structural adaptability alongside design tensions.

To address these barriers, two main interventions are proposed. First, the dissertation introduces "Tech Battles", a preparatory active learning experience designed to train students' "active mindset" in a low-stakes environment. Second, and central to this work, it presents the "Choose Your Own Adventure in CBL" (CYOA-CBL) framework. This novel framework redefines the traditional trade-off between structure and autonomy in CBL as a student-led choice, allowing teams to self-regulate their learning path, reduce the implementation load of teaching staff and increase CBL's replicability and flexibility in different contexts.

The framework was evaluated through an exploratory longitudinal study across two iterations of a mandatory, semester-long Master's course and further tested in an intensive, short-term extracurricular activity. Empirical evidence from student reflections, interviews, and observational notes suggests that CYOA-CBL offers a viable solution to accommodate diverse student needs within a single course architecture. The findings reveal that the framework acts as a safety net for students with lower ambiguity tolerance while providing the necessary freedom for motivated teams to experiment. Furthermore, the structure of CYOA-CBL helps instructors establish clear organization and manage course complexity effectively, while its core concepts prove easily adaptable across different subjects and educational environments. Finally, the research highlights the critical dependence of CBL success on the active engagement of Challenge Providers and the essential role of mentoring sessions with student teams. This thesis provides a model for Computer Science education based on scalable, flexible, and adaptable principles, contributing to the ongoing debate on cultivating essential professional dispositions alongside technical expertise.

Keywords

Challenge-Based Learning; Computer Science Education; Active Learning

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Chapter 1

Introduction

1.1 Context and purpose of the thesis

Contemporary society is experiencing an unprecedented era of digital transformation. The pervasiveness of information technologies has fundamentally reshaped not only industrial and social processes but also the very nature of knowledge itself. In particular, the recent and widespread adoption of Artificial Intelligence (AI) and Large Language Models (LLMs) has established a new paradigm in computing education: access to information and the automatic or computer supported generation of technical content and code have become immediately accessible [47].

In this evolving context, the established framework of 21st Century Skills - traditionally centered on the "4 Cs": Critical thinking, Communication, Collaboration, and Creativity [82] - is undergoing a significant adaptation. While there is general agreement that these skills remain essential for all students [54], their application is shifting. The focus, previously limited to human-to-human interaction, must now expand to a new collaborative paradigm consisting of "human, human, and AI" [122].

This evolution demands new specific competencies for computer science (CS) students and for example, recent scholarship identifies Prompt Engineering as an emerging skill essential for professional development in the Information Technology (IT) industry [37].

However, this integration presents challenges. Excessive reliance on AI can lead to dependencies, potentially hindering the development of core skills and dispositions like problem-solving and self-confidence, as observed in educational settings [117]. Furthermore, since AI models rely on datasets that may be insufficient or biased, the human role must shift from pure generation to critical auditing. The human operator

remains essential in judging the reliability of the output, refining machine-generated contributions through complex critical judgment - a capability AI cannot yet replicate [116].

Consequently, it is no longer sufficient for a CS graduate to possess only excellent technical competences. The contemporary job market demands CS graduates who combine deep technical expertise with a broad set of transversal competencies, such as critical thinking, complex problem-solving, teamwork, effective communication, and adaptability.

Despite this clear necessity, a significant skills and dispositions gap persists between the computing education offered by traditional university curricula and the demands of the professional landscape. Traditional lectures often prove inadequate in cultivating transversal competencies [110, 104]. To address this limitation, pedagogical research increasingly highlights alternative teaching approaches, particularly Active Learning, as effective solutions to bridge this gap [105].

Among these methodologies, Challenge-Based Learning (CBL) is gaining popularity in higher education for Computer Science and Engineering degrees [66]. CBL stands out among other X-Based learning approaches (such as Project-Based or Problem-Based Learning) by grounding the learning experience in real-world, open-ended challenges proposed by external actors. This methodology provides a rich ecosystem for developing both technical and transversal competencies such as collaboration, communication and critical thinking.

However, the widespread adoption of CBL faces significant implementation hurdles. While the theoretical benefits of CBL in computing education are clear, the practical application often proves resource-intensive and complex. The primary challenges addressed by this thesis stem from a lack of clear, scalable guidelines and the difficulty of adapting the methodology to different constraints [83, 33]. Specifically, the critical issues observed include:

1. **Student readiness and motivation:** students used to traditional lectures often lack the foundational dispositions required to handle the autonomy of CBL. This sudden exposure to open-ended challenges can generate significant anxiety, confusion, and resistance if not properly scaffolded. Furthermore there is a lack of flexible models that allow the level of difficulty and autonomy to be adjusted according to the specific context and student profiles.

2. **Resources and scalability:** CBL typically requires physical and digital infrastructure not always available. It also needs high staff-to-student ratios for

effective mentoring, making it challenging to implement in large courses without overwhelming the teaching staff.

3. **Structural adaptability:** courses are often highly tailored to specific contexts (e.g., a specific industry partner or university structure and ecosystem), making them difficult to transfer to different institutions or course formats (e.g., short courses).

Designing and implementing CBL courses requires substantial effort and some universities often lack the ideal conditions and necessary resources. The research landscape of CBL remains vaguely defined and fragmented, and most papers on CBL are descriptive, offering minimal or no conceptualization of the CBL framework [83]. There are still no clear procedures on how to develop a CBL course that is suitable and flexible enough for diverse contexts and a more in-depth exploration is needed.

1.1.1 Research questions and objectives

This research starts from the necessity to foster the right attitude in students to embrace active learning and effectively develop transversal competencies. While Challenge-Based Learning (CBL) is a powerful methodology for this purpose, its widespread implementation is often hindered by specific barriers mentioned before.

Recognizing that students often lack the necessary preparation for open-ended challenges, the prerequisite (or objective "zero" - O0) is analyzing and defining propaedeutic and preparatory activities. Serving as the foundation for all subsequent steps, these activities can introduce students to transversal competencies in a controlled environment before exposing them to the complexity of CBL.

Therefore, building upon the analysis of the critical success factors affecting CBL adoption, the subsequent objective (O1) of this thesis is to enable students to self-adapt CBL to match their different profiles, accounting for their varying attitudes, readiness, motivation and disposition toward transversal competencies.

Finally, to overcome the other identified barriers, this thesis aims to reduce the implementation load teaching staff faces when running CBL activities (O2) and increase CBL's replicability and flexibility in different contexts (O3). To do so, this thesis evaluates the "Choose Your Own Adventure in Challenge Based Learning" (CYOA-CBL), a novel pedagogical framework designed to: i) align with students' different motivations and dispositions; ii) optimize teaching capacity; iii) ensure

replicability, even in different contexts and lower adoption barriers of CBL through flexibility.

The doctoral thesis seeks to answer the following Research Questions (RQs):

1. **RQ1:** How can preparatory teaching methods be deployed to prepare computer science students to deal with the complexities of active learning?

2. **RQ2:** How can CBL be made more adaptable to a greater variety of student motivations, teaching contexts, and institutional resource constraints?

3. **RQ3:** How can teachers adapt CBL to let students fine-tune their learning experience without trading off control over the course?

These questions guide the selection and synthesis of the collected papers, each contributing a distinct piece of evidence toward establishing novel and effective ways to implement active learning models and align CS education with current needs.

1.2 Scoping

Four main delimitations frame the scope of this research.

First, the empirical studies presented in this dissertation are geographically and institutionally bounded to higher education courses conducted at the University of Trento, Italy. While the physical implementation was localized to a single academic institution, the target population comprises students from highly diverse academic and cultural backgrounds, including a significant proportion of international students. This multicultural diversity provides a rich and representative sample for examining student motivations, attitudes, and engagement regarding transversal competencies, even though institutional specifics should be kept in mind when extrapolating findings to other university systems.

Second, the evaluation of pedagogical feasibility is methodologically limited by the profile of the participating teaching staff. The educators responsible for implementing the interventions across the target courses were, in part, the same individuals involved in co-designing the "Choose Your Own Adventure in Challenge Based Learning" (CYOA-CBL) framework. While this dual role ensured high implementation fidelity, the finding that the framework is manageable and easy to adopt for educators is only partially verified and reflects a controlled, expert-led context rather than broad-scale implementation by neutral teachers.

Third, while this dissertation highlights numerous barriers to adoption and critical success factors associated with Challenge-Based Learning, it does not aim to solve all existing challenges within active learning pedagogy. Instead, it addresses a specific subset of these issues by proposing a novel framework designed to overcome several core obstacles identified in the context of computing education. This framework is not presented as a universal solution to all pedagogical friction points, but rather as one viable strategy for improving adaptability and manageability in CBL environments.

Fourth, the main focus of this dissertation is on the design, deployment, and evaluation of scaffolded, adaptable active learning framework. A direct, formal assessment or longitudinal measurement of actual student skill acquisition (specifically regarding transversal competencies) falls outside the defined scope of this research.

1.3 Methodology

The empirical testing of educational methodologies is inherently constrained by the temporal structure of university curricula. Since the target courses are offered only once per academic year, opportunities for experimental validation are naturally spaced out over time. To address this constraint, this research adopts the core principles of action research [5]: empirical findings and reflective insights generated from each implementation directly inform the ongoing inquiry, iteratively refining both the pedagogical interventions and the overall research design. Accordingly, the studies presented in this dissertation employ a mixed-methods strategy characterized by design, implementation, evaluation, and redesign within real educational settings to continuously evolve new educational practices.

The overall process was built upon the following steps:

1. Initial literature review and problem identification: the study started with an extensive literature review to establish the necessary state of the art regarding transversal competencies, active learning, and the documented challenges related to scalability and teaching capacity in active learning and CBL.

2. Preliminary framework design: based on the identified gaps, preliminary designs for key pedagogical frameworks were developed to support the progression strategy. In particular, the "Tech Battles" (a debates-based teaching method described in detail in Chapter 4) was designed as a preliminary approach to stimulate transversal competencies in a controlled, lower-complexity environment compared to a CBL course. It acted as a preparatory scaffolding tool to equip

students with the necessary skills and dispositions before entering the complexity of CBL. Then, the "Choose Your Own Adventure in Challenge Based Learning" (CYOA-CBL) framework was designed to structure a CBL experience that prioritizes adaptability.

3. Extended in-depth investigation: the research proceeded to an extended phase of in-class deployment, moving from pilot studies to full-scale, compulsory curricular courses. Tech Battles were implemented as decontextualized debates using for the first time Science Fiction narratives as starting point for the debates. This allowed students to train critical thinking and public speaking skills. CYOA-CBL was subsequently deployed and this step was critical for generating empirical data on the frameworks' impact on student learning.

4. Data analysis and interpretation: data collected during the implementation phases (including surveys, student reflections, and interview transcripts) were subjected to quantitative and qualitative analysis.

5. Validation across contexts: to ensure the robustness and replicability of the CYOA-CBL framework, the research strategy involved testing it across distinct implementation settings representing different extremes of implementation possibilities — specifically, twice within standard semester-long curricular courses and once during an intensive short course. This multi-context validation sustained the framework's claim of replicability and adaptability despite structural and resource variations.

6. Refinement and iterations: findings and insights obtained from data analysis and cross-context validation continuously informed the framework design. This led to specific refinements and improvements, particularly regarding the CYOA-CBL structure (resulting in the second iteration of CYOA-CBL), strengthening the empirical validation and practical relevance of the final contributions.

1.4 Contributions to Computing Education

International computing curriculum guidelines strongly advocate integrating transversal competencies with technical knowledge [40, 57], a goal effectively supported by active and challenge-based learning [83]. However, recent literature indicates that widespread adoption of these pedagogical approaches remains hindered by student resistance to

ambiguity, structural rigidity, and operational scalability barriers [104]. To address these central friction points, the research presented in this dissertation yields several original contributions to the field of Computer Science Education:

The Tech Battles methodology: the definition of a preparatory active learning method based on debating. The proposed method leverages Science Fiction short stories to scaffold students' preparation in transversal competencies such as public speaking and critical thinking. This can act as a preparatory activity for students before they engage in the complexity of more sophisticated active learning educational activities, such as a full CBL course.

The CYOA-CBL framework: *the primary contribution of the thesis is the theoretical development and empirical validation of the "Choose Your Own Adventure in Challenge Based Learning" (CYOA-CBL) framework.* This represents a novel pedagogical architecture explicitly designed to address the scalability and adaptability issues inherent in traditional CBL implementations, balancing pedagogical structure with learner autonomy.

Evidence of feasibility: the thesis provides empirical evidence obtained from evaluating the CYOA-CBL framework within a mandatory curricular course. The findings indicate the framework's feasibility for the teaching team, as well as its understanding from a student perspective, who successfully navigated and comprehended the process.

Evidence of adaptability: the thesis provides empirical evidence obtained from evaluating the framework in diverse educational contexts, ranging from intensive short-term challenges (e.g., ECIU University challenges [1]) to standard mandatory academic courses. This demonstrates the framework's replicability across different constraints and university structures.

While the overarching contribution of this dissertation is primarily empirical - offering actionable strategies to mitigate different barriers hindering active learning adoption — it also yields an incremental theoretical advancement. Specifically, it shifts the understanding of Challenge-Based Learning away from the traditional binary trade-off (" structure" versus "open" CBL) [11] toward a broader, multi-dimensional trade-off continuum.

[1] See `https://engage.eciu.eu/learning-opportunity/89fad7d0-1154-422a-a07d-6781cc5df97e/orienteering-unlocking-new-potential-for-a-niche-sport-club` (last access 2026/01/11).

1.5 List of publications

The research presented in this dissertation is grounded in a collection of peer-reviewed papers published by flagship conferences in the fields of Engineering Education, where Challenge-Based Learning (CBL) is widely adopted (e.g., IEEE Frontiers in Education), and Computing Education (e.g., ACM Technical Symposium on Computer Science Education SIGCSE). Additionally, specific findings were also presented to the community of practice of CBL like the International CBL Conference. The following list presents all publications of my doctoral journey and part of them are used in this doctoral dissertation.

Peer-reviewed papers:

- **Enabling Computer Science Students to Choose Their Own Adventure in a Mandatory and Curricular Challenge-Based Learning Course**
  J. Lucchetta, S. Turrini, M. Stoycheva, M. Marchese, and L. Angeli
  Published in 2024 IEEE Frontiers in Education Conference (FIE), Washington, DC, USA, 2024, pp. 1-8, doi: 10.1109/FIE61694.2024.10893335

- **Fair Tales of Interdisciplinary Learning: Unveiling Students Voices and Competencies Evolution in a Challenge-Based Learning Summer School**
  T. Carraro, J. Lucchetta, G. Varas, M. Stoycheva, M. Marchese, and L. Angeli
  Published in 2024 IEEE Frontiers in Education Conference (FIE), Washington, DC, USA, 2024, pp. 1-9, doi: 10.1109/FIE61694.2024.10892819

- **Revisiting Tech Battles Using Science Fiction: Methodological Implications and First Impressions**
  J. Lucchetta, T. Carraro, M. Stoycheva, and L. Angeli
  Published in 2024 IEEE Global Engineering Education Conference (EDUCON), Kos Island, Greece, 2024, pp. 1-5, doi: 10.1109/EDUCON60312.2024.10578814

- **Choose Your Own Adventure: Empowering Students to Combine Structured and Open Challenge-Based Learning**
  J. Lucchetta, T. Carraro, M. Stoycheva, M. Marchese, and L. Angeli
  Published in 2023 IEEE Frontiers in Education Conference (FIE), College Station, TX, USA, 2023, pp. 1-5, doi: 10.1109/FIE58773.2023.10343390

Peer-reviewed contributions (non-papers):

- **Strategies for Implementing Challenge-Based Learning in Short Courses: Developing Professional Skills Through Challenges**

J. Lucchetta, S. Turrini, M. Marchese, and L. Angeli
Published in Proceedings of the 57th ACM Technical Symposium on Computer Science Education V.2 (SIGCSE TS 2026), February 18–21, 2026, St. Louis, MO, USA. ACM, New York, NY, USA, 2 pages. `https://doi.org/10.1145/3770761.3777287`

- **How Can We Make Challenge-Based Learning in Computer Science More Adaptable?**
  J. Lucchetta
  Published in Proceedings of the 30th ACM Conference on Innovation and Technology in Computer Science Education V. 2 (ITiCSE 2025). Association for Computing Machinery, New York, NY, USA, 822–823, doi: 10.1145/3724389.3731290

- **Leveraging Science Fiction to Prepare Students for Tech Battles**
  J. Lucchetta, A. Saiani, M. Stoycheva, and L. Angeli
  Published in Proceedings of the 55th ACM Technical Symposium on Computer Science Education V. 2 (SIGCSE 2024). Association for Computing Machinery, New York, NY, USA, 1728–1729, doi: 10.1145/3626253.3635532

Contributions subject to editorial review:

- **How do external actors become Challenge Providers in a Challenge-Based Learning curricular course in higher education?**
  S. Turrini, J. Lucchetta, L. Angeli, and M. Marchese,
  Published in International CBL Conference - CBL 2025, Eindhoven, The Netherlands, doi: 10.5281/zenodo.15675039

Relevant presentations:

- **Choose your own adventure - A Flexible and Novel Six-Phase Approach Applied in an ECIU University Challenge**
  J. Lucchetta
  Presented during the ECIU Forum 2025, Trento, Italy, doi: 10.5281/zenodo.15675133

Manuscript based on Chapter 6 currently nearly complete and to be submitted to the international journal ACM Transactions on Computing Education (TOCE) - Appendix F:

- **Towards enabling learner self-regulation for non-technical course**
  J. Lucchetta, S. Turrini, M. Marchese, and L. Angeli

1.6 Structure of the thesis

This doctoral dissertation is presented in the format of a compilation of articles. Chapters 1, 2, 3, and 8 constitute original contributions written specifically for this dissertation to provide overarching contextual, methodological, and reflective framing. The remaining chapters are based on peer-reviewed articles previously published by the author and co-authors. They have been adapted here to enhance readability and ensure coherence across the thesis.

The thesis is organized into eight chapters:

- Chapter 1 (Introduction): this chapter establishes the research context, outlines the problem statement within Challenge-Based Learning, details the research questions, and presents the methodological framework employed across the studies.

- Chapter 2 (State of the art): this chapter provides a comprehensive overview of existing literature on CS education, the skills and dispositions gap in CS education, Active Learning methodologies, and the current limitations of Challenge-Based Learning.

- Chapter 3 (Research rationale and methodology): this chapter defines the overarching pedagogical rationale, the methodology of this dissertation and the logical narrative connecting the different studies.

- Chapter 4 (Leveraging Tech Battles to prepare students for transversal competencies): this chapter explore the "Tech Battles" methodology and investigate the use of Science Fiction as an enabling tool to prepare students for CBL.

- Chapters 5-6-7 (The intervention): these chapters present the core methodological contribution. It introduces the design of the CYOA-CBL framework (Chapter 5). Chapter 6 analyzes its two implementation and the analysis of the data gathered during these experiences. Furthermore, with Chapter 7, the thesis strengthens the adaptability of the method when applied to short course formats.

- Chapter 8 (Discussion and conclusions): this chapter expands the perspective on the educational ecosystem by analyzing the crucial role of external actors in a CBL course, synthesizes the achieved results, discusses their broader implications for the future of CS Education, and outlines potential directions for future research.

Chapter 2

State of the art

2.1 The evolving landscape of Computer Science education

Digital transformation has profoundly impacted various aspects of human life, forcing the education sector to question whether traditional teaching methods remain adequate in an era of easily accessible and abundant information. In the seminal paper describing Challenge-Based Learning, Nichols et al. [77] described traditional teaching as "increasingly ineffective" in a time where knowledge acquisition is no longer the sole goal. The enormous amount of information available on the Web, including Open Educational Resources (OER) and the new wave of Generative Artificial Intelligence tools for education, has shifted the focus of teaching and learning from merely obtaining knowledge to critically assessing it [82].

Employers are increasingly seeking individuals who combine deep technical expertise with broad transversal competencies such as communication, conflict resolution, resource management, and entrepreneurship mindset [120, 72]. Consequently, the focus of computing curricula, which was traditionally centered on technical knowledge, has shifted. In recent years, the computing field and the related work environment have given more importance to professional dispositions, attitudes, and transversal competencies [40].

This transition was formally embraced by the Information Technology Curricula 2017 (IT2017) report [93], which advocated for a move away from the traditional Knowledge Area/Knowledge Unit model toward Competency-Based Learning. This pivot was driven by the reality that the vast majority of graduates from information technology degree programs enter the industry and the workplace immediately upon

graduation. To ensure career readiness, students in higher education must develop a range of qualities that extend beyond mere technical recall. The IT2017 [93] report explicitly defined this relationship through the following conceptual equation:

$$\text{Competency} = \text{Knowledge} + \text{Skills} + \text{Dispositions} \ldots \text{in Context} \tag{2.1}$$

In this view, knowledge is only one component of the broader idea of competency. The three dimensions can be detailed as follows:

- Knowledge is the awareness and understanding of core concepts and content. It typically receives the most attention from teachers when designing syllabi and from departments when developing program curricula. It represents the theoretical foundation of the discipline.
- Skills refer to capabilities and strategies that develop over time through deliberate practice and interactions with others. Skills require engagement in higher-order cognitive activities, and represent the practical application of knowledge.
- Dispositions encompass socio-emotional skills, behaviors, and attitudes that characterize the inclination to carry out tasks and the sensitivity to know when and how to engage in those tasks. As noted in the IT2017 report, this dimension is often the most challenging for academics, as traditional computing faculty may overlook or struggle to integrate dispositions into standard educational settings.

This shift highlights that while knowledge remains foundational, it is no longer sufficient for a graduate to possess only technical depth [93]. Skills and dispositions are what ultimately bridge the gap between academic preparation and professional excellence.

After some years, the Computer Science Curricula 2023 confirmed again this need and stated that graduates should develop essential skills such as problem-solving and analytical reasoning, as well as professional dispositions like teamwork and adaptability [57]. These abilities are fundamental not only for success in the workplace but also for long-term professional growth and effectiveness. This approach ensures that all graduates of computing programs have the preparation to be effective for specific career paths.

In this dissertation, I use *"transversal competencies"* as the overarching term for non-domain-specific abilities (such as critical thinking, collaboration, and communication). Within these competencies, I specifically refer to *"professional*

dispositions" (or simply "dispositions") when addressing students' attitudes, self-regulation, tolerance for ambiguity, and proactive mindset.

Despite this clear curricular mandate, widespread instructional change within higher education remains notably slow [39]. Many instructors in Computer Science, Information Technology, and Software Engineering (CS/IT/SE) programs continue to rely predominantly on traditional, teacher-centered methods, driven by systemic institutional challenges and historical practices deeply rooted in engineering and computing departments [104]. While computing faculty have gradually embraced student-centered practices to some degree, achieving higher adoption rates remains essential to optimizing student retention and long-term learning outcomes [43].

2.2 Active learning

Active learning is generally defined as any instructional method that engages students in the learning process, requiring them to perform meaningful activities and think critically about what they are doing [13]. The core distinction of this approach is the shift from a teacher-centered instruction to a student-centered model. In a teacher-centered lecture, students passively receive information while in a student-centered class students become the main actors of their educational journey [86, 18].

The adoption of these methodologies is driven by their proven potential to enhance motivation, academic performance, and retention rates. By exposing students to "quasi-real" situations or simulated professional scenarios, active learning allows them to practice technical skills under supervision while simultaneously developing in-demand transversal competencies. Research indicates that this approach effectively nurtures essential skills such as teamwork and problem-solving, better preparing graduates for the challenges of the real working environment [50].

The landscape of active learning in Computer Science and Engineering education is vast. The most popular strategies that have resulted in enhanced learning outcomes include the Flipped Classroom, Experiential Learning, Concept Tests, Think-Pair-Share, Gamification, Role-Playing, and the so-called "X-based" learning methodologies – such as Problem-Based Learning (PBL) and Project-Based Learning (PjBL) [1, 22].

2.2.1 Pedagogical foundation and learning theories

Active learning shares characteristics of several learning theories and pedagogical foundations that prioritize learners' active construction of meaning and engagement with real problems. The main theories behind active learning are constructivist, its social evolution, and experiential learning theories.

Constructivism

Constructivism in education traces to psychological and philosophical work that reframed knowledge as actively constructed by learners rather than transmitted by teachers. Key works include Jean Piaget's individual cognitive construction and Lev Vygotsky's social mediation of development [41, 51].

While constructivist ideas have ancient roots, Jean Piaget was the first to systematically apply them to define a theory on cognitive development that views learning as the result of mental construction [85]. Learning takes place when new information is built into and added onto an individual's current structure of knowledge, understanding and skills. Students learn best when they actively construct their own understanding [87].

Constructivism is defined as an active, non-linear, and iterative process where learners build meaning through ongoing interaction with both their social and physical environments. Rather than reducing learning to behavioral conditioning or merely mapping out static cognitive stages, this psychological theory of learning explains how language, mental structures, and comprehension emerge [41]. Learning is defined not as a passive absorption of external behaviors, but as a complex, evolutionary process.

Social constructivism

The constructivist assumption that learners build understanding from experience is central to most descriptions of active methodologies, and socio-interactionist perspectives add the role of social mediation and dialogue in learning. The theory proposed by Vygotsky [113] and often described as social constructivism, emphasizes the interaction between the learner and others [87]. Rather than viewing knowledge acquisition as a purely solitary cognitive endeavor, social constructivism posits that meaning is a collaborative and culturally situated product. From this perspective, knowledge is continuously co-constructed and mutually agreed upon through interpersonal interaction and shared comprehension [51]. Social constructivism

gives a high priority to language in the process of intellectual development. Dialogue becomes the vehicle by which ideas are considered, shared and developed [87].

Experiential learning

Another fundamental pillar of active learning is rooted in Experiential Learning Theory (ELT). Its foundations can be traced back to the seminal work of Dewey, Lewin, and Piaget, and were later formalized by David Kolb into a four-stage learning cycle and associated learning styles [56]. Kolb defines experience as the primary source of learning and development. He describes a recursive process driven by the interaction between the individual and the environment. This cycle is composed of four distinct stages:

- Concrete experience - engaging in a new experience or reinterpreting an existing one;
- Reflective observation - reflecting on the experience from multiple perspectives;
- Abstract conceptualization - forming new ideas or modifying existing abstract concepts based on reflection;
- Active experimentation - applying new theories to the world to see what happens.

In this cycle, experience acts as a catalyst, providing concrete engagement and spaces for experimentation that bridge cognitive processes with professional practices. Kolb articulated that these stages, along with a set of learner preferences called "learning styles" that inform how individuals navigate the cycle, are essential for deep learning [55, 56].

This theoretical perspective is particularly relevant to the field of Information Technology (IT). Specifically, the IT2017 curriculum guidelines highlighted that it is not enough to simply attend courses and read books. Hands-on, experiential learning is essential for information technology. Students that "learn by doing" through "live lab" exercises are highly prized [93]. This underscores that in the IT field, the Kolb's cycle is not just a pedagogical preference, but a professional necessity. By engaging in "live labs", students can bridge the gap between abstract conceptualization and real-world application, developing the practical expertise that the industry currently demands.

2.2.2 Debates as a pedagogical tool

Within the several active learning strategies, debates represent a particularly interesting case. In-class debates are commonly used in humanities and law to promote interaction

and engagement. In the computing domain, while literature reports some examples as far back as 2002 [2, 84], their use remains rare.

Despite this limited adoption, debates have been presented as a solid way to prepare students to defend their ideas in both industry and research settings [65]. They help students develop skills such as synthesising information, self-directed learning, critical thinking, and verbal communication [2].

The pedagogical effectiveness of debates is deeply rooted in the principles of social constructivism described above. Social constructivism shifts the focus from the individual learner to the collective, emphasizing that knowledge is co-constructed through social interaction. As noted by Pritchard, the emphasis is placed upon interaction between the learner and others and dialogue becomes the vehicle by which ideas are considered, shared and developed [87].

In the context of a debate, dialogue serves as the primary instrument for a social negotiation. It is through the debate of opposing viewpoints that students are forced to articulate their reasoning, listen to alternative perspectives, and refine their own understanding. Consequently, the debate becomes more than just a communication exercise, it is a socially-mediated cognitive process where the exchange of language allows for the negotiation of meaning and the development of higher-order critical thinking [16].

However, the effectiveness of debates critically hinges on the selection of the topic. A good topic should encourage students to deepen their knowledge but also feature clear opposing sides to ease the understanding of distinct positions [48]. If the topic is inappropriate, it may cause a loss of motivation [123].

To address the difficulty of topic selection and student engagement in STEM debates, recent literature suggests the integration of Science Fiction (Sci-Fi). Initiatives like MIT Technology Review's "Twelve Tomorrows" and Intel's "The Tomorrow Project" indicate a growing interest in leveraging Sci-Fi to envision technology's societal integration [106].

Crucially, work by Vrasidas et al. [111] showed that Science Fiction stories help students form relevant emotional links that aid them in understanding learning activities. These narratives enable students to develop research, debating, and decision-making skills by establishing connections between literature and technological development. In computing education specifically, Sci-Fi has been argued to enhance student engagement and creativity [53].

Within the Human-Computer Interaction (CHI) community, this narrative approach evolves into Design Fiction. This method goes beyond standard storytelling by focusing on futuristic objects, innovations or services [102]. This approach forces students to

confront the practical and ethical implications of a technology as if it were reality, creating a tangible context for critique [10].

2.2.3 Popular active learning methodologies

Within the domain of STEM and Computing education, a specific family of active learning methodologies sometimes referred to as X-Based Learning (XBL) [9] has gained particular prominence. This classification includes several methodologies like Project-Based Learning (PjBL), Problem-Based Learning (PbBL), Case-Based Learning (CsBL), and, most recently, Challenge-Based Learning (CBL).

Most of the X-based methodologies require students to collaborate actively, reflecting the core principles of social constructivism: learning is not an isolated process but a collective construction of meaning [113]. Perna et al. emphasize that these practices prioritize social interaction, the creation of shared artifacts, and close collaboration between learners and experts [83]. This approach creates a direct bridge to the professional IT sector, particularly within modern computing practices where frameworks such as Agile methodologies demand professionals to work in teams where solutions emerge from collective thinking rather than individual effort [96].

Each method offers distinct advantages depending on the pedagogical goals [103]:

- Project-Based Learning (PjBL) focuses on students working on a project over an extended period, culminating in a final product or presentation. It enhances creativity and teamwork skills, allowing students to apply theoretical knowledge to build tangible solutions or products.

- Problem-Based Learning (PbBL) centers student learning on the resolution of problems. It significantly improves critical thinking and fosters habits of self-directed and lifelong learning.

- Case-Based Learning (CsBL) involves the analysis of specific historical or hypothetical "cases" – narratives that present a dilemma or a decision-making scenario. Students apply theoretical knowledge to analyze the situation and propose solutions based on evidence. It connects abstract theory and practice, helping students contextualize knowledge through relevant and real scenarios [69].

- Challenge-Based Learning (CBL) builds upon the previous methods but adds layers of urgency and societal relevance. It goes beyond the others as the challenge is not fully predefined, as learners and the community members participate in its

co-creation. CBL asks learners to formulate a problem and relevant questions, to investigate compelling issues, to reflect on their learning and the impact of their actions, and then to present their solutions to a multi-actor audience. It develops high-level transversal competencies sought by employers – such as resilience, innovation, and ethical decision-making – while fostering a sense of social responsibility and agency.

While the terminology is often used interchangeably, distinct nuances separate these approaches. The differences can be presented based on different dimensions. For example, the goal of PjBL is to complete a project and the process is often more linear and defined. Conversely, the goal of PBL is to solve problems and students have to acquire the knowledge necessary to solve it while CBL addresses real problems and the process is more complex. Then in CsBL and PBL, the problems are often carefully created by the instructor to ensure specific learning outcomes are met. In contrast, CBL embraces a higher degree of ambiguity. With CBL, there is not a clear problem to solve, but a real and open challenge. These challenges often lack a single "correct" solution, requiring students to navigate uncertainty. With PjBL, the teacher acts as a project manager; in PBL, teachers serve as a guide; and in CBL, they operate as teachers, mentors and organizers [103, 36]. PjBL and PBL are well-established methodologies with decades of literature and standardized frameworks. CBL conversely, is a younger pedagogy. While it offers greater potential for societal impact, it requires more careful design to manage the inherent chaos and potential ethical implications of working with real external actors [103, 33].

2.2.4 Challenge-Based Learning (CBL)

Challenge-Based Learning (CBL) emerges as one of the most promising methodologies within the X-Based family. Nichols and Cator proposed the initial definition, describing it as "a [...] multidisciplinary approach [...] that encourages students to [...] solve real-world problems. [CBL] is collaborative and hands-on, asking students to work with peers, teachers, and experts [...] to take action" [77].

Unlike Problem-Based or Project-Based Learning, CBL is distinct due to the nature of the stimulus: students are engaged in a "challenge" often provided by an external actor (commonly referred to as the "Challenge Provider"). Crucially, students possess a higher degree of autonomy; they are not just solving a given problem but are active participants in defining the specific shade of their challenge and setting their own goals [66, 112].

The traditional pedagogical architecture of CBL is built upon a three-phase framework: Engage, Investigate, and Act [78]. These stages closely mirror the iterative cycle of Kolb's Experiential Learning Theory (ELT) described above, which posits that knowledge is created through the transformation of experience [56]. Each CBL's phase contains activities designed to prepare learners for the subsequent stage:

- Engage: learners move from an abstract "Big Idea" to a concrete and actionable challenge using an essential questioning process. The goal is to personally connect with the content and foster ownership of the problem.

- Investigate: building from the challenge, learners develop contextualized learning experiences and conduct rigorous, content-based research. This creates the theoretical foundation necessary for sustainable solutions.

- Act: evidence-based solutions are developed and implemented with an authentic audience. The results are then evaluated, combining a desire to make a difference with a demonstration of content mastery.

Beyond this structure, CBL is characterized by specific operational traits that distinguish it from standard coursework. Challenges are proposed by external actors (not-for-profit organizations, industry, municipalities, etc.) and are connected to real and societal needs without a pre-defined solution. Students work in teams and teams draw on multiple disciplinary perspectives to develop viable solutions. Challenges consider social implications, not just technical or commercial outcomes. The process aims for implemented solutions (e.g., a pilot, service, or product) rather than theoretical reports. Teachers transition from instructors to mentors, providing feedback and support while leaving substantive choices to the learners [103].

According to Perna et al., CBL integrates characteristics from progressive, constructivist, sociocultural, experiential, service, critical, and constructionist learning theories. These theories highlight active, experiential, relational, contextual, self-regulated, and practical learning that occurs within individuals, communities, and organizations [83].

Despite its potential, CBL remains in an emerging phase, and its widespread adoption faces significant hurdles. Leijon et al. [67] and Perna et al. [83] highlight that research in this area is still limited, and many institutions struggle to deploy CBL effectively.

Success in CBL is not automatically guaranteed; empirical evidence shows a strong interdependency with learners' prior knowledge, intrinsic motivation [63], and the support structures provided by teachers and external challenge providers [73, 103].

Within the specific domain of Computing Education Research, a primary benchmark for operational friction points is provided by Suleiman et al. [104]. Their systematic analysis established a baseline of critical challenges in Project-Based Learning (PjBL) environments, categorized across eight key dimensions: *teaching workload, student workload, confidence and motivation, external stakeholders, course organization, project management, teamwork,* and *assessment* [104]. Because CBL represents an evolution of PjBL that shares its inductive and collaborative pedagogical foundation, these operational bottlenecks persist and are often intensified in CBL settings.

While Suleiman et al.'s taxonomy provides a robust domain-specific foundation for computing education, it represents one of several ways to conceptualize CBL implementation barriers. In the broader educational literature on CBL, researchers have proposed alternative classifications of these adoption hurdles [33]. To establish a structured foundation for this dissertation, these multifaceted barriers are synthesized and categorized into three core macro-dimensions: *student readiness and motivation*, *necessary resources and scalability*, and *structural adaptability and design tensions*.

Barrier to adoption: student readiness and motivation

The first barrier lies in the students themselves. While the pedagogical benefits of CBL are well documented, its success is heavily dependent on student attitudes and dispositions. Unlike traditional instruction, where passivity is often tolerated, CBL requires students to exhibit high levels of proactiveness, resilience, and tolerance for ambiguity [103].

The literature consistently reports that students frequently resist active learning methodologies. This phenomenon arises because these methods disrupt the traditional didactic contract [89, 81, 101] and require students to actively construct knowledge that often leads to uncertainty in the absence of authoritative guidance and demands more effort than traditional classes. As documented by Felder and Brent [38], transitioning from a passive lecture model to an autonomous active learning environment represents a major developmental hurdle for engineering and computing students. Instructors frequently encounter strong aversion, skepticism, or even hostility when students feel that familiar instructional structures are suddenly withdrawn [38, 99].

A previous work from Deslauriers et al. demonstrated that students in active

learning environments often report lower satisfaction and a lower feeling of learning compared to passive lectures, even when their actual learning outcomes are significantly higher [28]. The authors attribute this to the increased cognitive load: active learning is harder, and this mental effort is often misinterpreted by students as poor instruction [28]. CBL courses are frequently the cause of student frustration, especially at the beginning. Doulougeri et al. [32] identified six frequent difficulties, including narrowing down broad challenges, managing group processes, and self-regulating time. In mandatory courses, where intrinsic motivation varies, these difficulties can be exacerbated.

To understand this friction, it is useful to adopt the lens of Self-Determination Theory (SDT) developed by Deci and Ryan [91]. SDT provides a psychological framework for understanding how motivation emerges and is sustained. SDT distinguishes between intrinsic and extrinsic motivation. It identifies three basic psychological needs essential to human development and wellbeing: autonomy (a sense of volition and control), competence (a sense of mastery and efficacy), and relatedness (a sense of connection and belonging). When these needs are met, learners are more likely to experience intrinsic motivation and so engage in learning because it feels meaningful, interesting, or aligned with personal values and goals [92]. Intrinsic motivation refers to engaging in an activity for its inherent satisfaction, whereas extrinsic motivation involves performing an activity to attain a separable outcome (e.g., grades, credits, or avoiding failure) [91]. CBL implies a shift in engagement, as the framework is inherently designed to rely on and foster intrinsically motivated learners rather than passive recipients of information [77, 91]. However, in mandatory engineering courses, the student population is heterogeneous. Many students may be primarily extrinsically motivated, focusing on efficiency and grade maximization. Research suggests that when extrinsically motivated students are faced with the open-ended nature of CBL, they may adopt a "surface approach" to learning, seeking the path of least resistance rather than engaging in deep exploration [97]. Recent findings by Michel et al. [74] show that behavioral engagement (e.g., investing extra effort, preparing for meetings) significantly predicts students' self-efficacy beliefs. This suggests that confidence in CBL is not just a prerequisite for action, but a result of it. Students who do not actively invest extra effort fail to develop the sense of mastery required for the course, creating a vicious cycle of disengagement [74].

Another central friction point is the tolerance for ambiguity. CBL exposes students to situations of uncertainty and, in some cases, tolerance of failure, which helps them to develop resilience [71]. In traditional engineering education, problems are often

well-structured with clear parameters. CBL, conversely, deals with wicked problems that are ill-defined. Some students with low tolerance for ambiguity may react to this openness with anxiety rather than excitement. Membrillo-Hernández et al. [71] noted that when students were asked about the worst features of CBL, they cited the high uncertainty and the strange didactic experience as primary sources of distress. This highlights the critical role of Self-Regulated Learning (SRL). As noted by Doulougeri et al. [34], SRL is a key pedagogical principle of CBL in engineering curricula because students bear the primary responsibility for planning and evaluating their progress. Doyle [35] argues that resistance in student-center environments often stems from a fear of the unknown and a lack of control. Without these dispositions or an adequate scaffolding to support these students, the "freedom" of CBL can result in paralysis or disengagement.

To prevent such outcomes, Jerome Bruner and colleagues introduced the concept of scaffolding in education to prevent learners from becoming overwhelmed [119]. Scaffolding involves temporary support, such as guided prompts, expert tools, or peer collaboration, that helps students tackle tasks they cannot yet do independently. This support bridges the Zone of Proximal Development (ZPD), a key idea from Lev Vygotsky's social constructivism theory [17, 113]. By addressing the ZPD, educators provide the necessary assistance to guide students turning potential frustration into a constructive learning experience [121].

Students have diverse needs, highlighting the importance of personalized and adaptive learning environments to effectively support them [52]. A one-size-fits-all approach fails to address the wide range of student profiles in a CBL environment. Therefore, creating tailored and supportive learning experiences is crucial, as enhanced engagement consistently leads to better outcomes [73].

Barrier to adoption: necessary resources and scalability

Implementing CBL requires significant resources, including high staff-to-student ratios for mentoring and the complex management of external stakeholders [83]. This operational complexity creates a bottleneck for scalability.

The CBL process requires a new teacher profile. Membrillo-Hernández [71] describes this profile as multifaceted: the educator must be an inspiring mentor, a challenge designer, an evaluator of competencies, and an expert linked to the professional environment. Recognizing that these traits rarely coexist in a single individual, Eldebo et al. identified three distinct roles necessary for CBL execution: the academic teacher,

the coach, and the organizer, which has been called "Teamcher" [36].

However, establishing such a specialized team presents a structural vulnerability. Courses often face staff turnover, and sustainable curricula cannot depend exclusively on a small circle of highly experienced practitioners. Furthermore, not all universities possess the teaching capacity or funds to support this "Teamcher" model. As a result, the feasibility of CBL often appears limited to elite environments with abundant resources, creating a barrier for standard institutions. This dependency makes scalability particularly difficult, especially for large, compulsory courses where high-touch mentoring is logistically unfeasible.

The resource burden of CBL goes beyond human capital to include physical and digital infrastructure. Traditional lecture halls with fixed seating often clash with CBL's fluid, collaborative nature. Effective CBL implementation requires flexible spaces that support quick shifts between individual work, group brainstorming, and plenary discussions [77, 78]. In engineering, this often means access to specialized laboratories or "maker spaces" for prototyping solutions. Additionally, the digital dimension introduces further technical demands. Successful CBL depends on robust IT infrastructure, including collaborative platforms for project management and specialized software or simulations that enable stakeholder engagement and digital prototyping [77, 31]. In resource-constrained institutions, the absence of these tools can reduce the authenticity of challenge experiences, widening the gap between elite and standard educational settings.

Barrier to adoption: structural adaptability and design tensions

Finally, there is an inherent tension in the pedagogical design of CBL regarding the balance between freedom and control.

As discussed by Bombaerts et al. [11], there is a trade-off between "structured" and "open" CBL. Structured approaches to CBL are easier to assess, more comfortable, and favor depth while open approaches are more demanding, better reflect the ambiguity of real-world challenges, and encourage creativity. Currently, the choice between these approaches is made by instructors during the course design phase, before the course begins and without prior knowledge of the students. This can be problematic, as the selected approach may not align with students' motivations or learning preferences, potentially impacting students' engagement and effectiveness. Openness, independence, and self-responsibility are often unfamiliar to students, leading to the difficulties discussed in Section 2.2.4 [73, 103].

Then, most literature focuses on long-term implementations. There is a specific lack of models capable of delivering meaningful learning experiences within limited timeframes (e.g., short modules or intensive weeks) or adapting to different institutional constraints [64, 114].

As mentioned above, CBL redefines the educator's role, and empirical studies consistently emphasize the need for teacher professional development. This systemic role shift poses significant challenges, positioning the tutor as the most "crucial resource" for students facing open-ended challenges [31, 36]. To succeed, teachers need support to become effective coaches, as the transition demands new facilitation skills [31]. This shift can be eased by using materials and tools that both reduce teachers' cognitive load and provide concrete artifacts to anchor coaching practices [107]. By scaffolding teacher-student interactions, these tools help educators develop the relevant competencies required for a successful CBL environment.

While these barriers underscore the need for longitudinal research and adaptable frameworks, other challenges — such as evaluating the transversal competencies students acquire through CBL and active learning methodologies [98] — remain beyond the scope of this dissertation.

Chapter 3

Research rationale and methodology

This chapter outlines the overarching pedagogical rationale guiding the structure of this doctoral dissertation. It specifically explains the narrative linking the individual studies, the design choices, and the specific research methodologies employed throughout the doctoral period related to this work. The primary objective is to clarify why these particular pedagogical interventions were chosen, how they interconnect, and the conceptual logic that binds them into a coherent research framework along with the methodologies applied in each study.

3.1 Goals of the dissertation

As detailed in Chapter 2, technical proficiency alone is no longer sufficient in the context of engineering and computing education. The complexity of real-world problems demands future professionals who possess transversal competencies such as critical thinking, adaptability, effective communication, and the ability to navigate ambiguity.

Although Challenge-Based Learning (CBL) is widely recognized in the literature as a key active learning methodology for fostering these competencies, its implementation creates a complex ecosystem with significant challenges. Chapter 2 highlights three barriers to adoption addressed in this dissertation: student readiness and motivation, the necessary resources for implementation, and structural adaptability.

Consequently, the overall aim of this doctoral thesis is to deconstruct these barriers and identify strategies to enhance the adaptability of CBL. The goal of my doctoral work is twofold: to enhance the methodology's accessibility and engagement from the student's perspective, and to improve its adoption, sustainability and manageability for educators and staff responsible for delivering the courses.

Based on this general goal, I have identified three research questions:

- RQ1: How can preparatory teaching methods be deployed to prepare computer science students to deal with the complexities of active learning?
- RQ2: How can CBL be made more adaptable to a greater variety of student motivations, teaching contexts, and institutional resource constraints?
- RQ3: How can teachers adapt CBL to let students fine-tune their learning experience without trading off control over the course?

To answer these questions, I have identified four objectives and possible interventions:

- O0: identify strategies to prepare students for CBL;
- O1: enable students to self-adapt CBL to match their different profiles;
- O2: reduce the implementation load teaching staff faces when running CBL activities;
- O3: increase CBL's replicability and flexibility in different contexts.

3.2 Methodology of the dissertation

This dissertation adopts an action research framework, relying primarily on qualitative methods, supported and enriched by descriptive statistics.

According to McNiff and Whitehead, action research is a practical approach to examining learning by critically assessing professional practice against set standards. If the practice meets expectations, researchers should explain why and provide supporting evidence. If improvements are needed, the method directs researchers to take action to enhance their practice and then produce evidence showing how the practice has improved [70, 75, 21]. By framing my Doctoral experience through this lens, the development, implementation, and evaluation of the educational design are treated not as static events, but as dynamic, evolving practices. Action research is a practice that involves collecting data, reflecting on actions based on that data, generating evidence from the data, and making knowledge claims grounded in conclusions supported by validated evidence [70]. My research is inspired by iterative action research cycles, each comprising distinct but interconnected phases that link planning, action,

observation, and reflection to enhance practice. While classic three or four-stage and spiral models vary in detail and emphasis, they both emphasize iteration, data-driven decision-making, and practitioner ownership [118, 21]. Accordingly, this dissertation compiles several works involving continuous iterative refinement of methodologies based on action research principles. The rationale for changes between iterations is supported by empirical evidence gathered in the previous cycle. This evolutionary process aims to develop a final educational model that is robust, contextually relevant, and validated through field testing.

While this study employs descriptive statistics as a supporting tool, the nature of this research is prevalently qualitative. This choice is to value, and analyze in depth the specific, highly contextualized experiences of the participants within the field [90]. Qualitative data forms the core of this research, capturing the subjective experiences, nuances, and deeper meanings behind participants' engagement.

Quantitative metrics are highly effective at mapping what occurs, but they struggle to capture why it occurs [49, 27]. Qualitative inquiry delves into the reasons behind human behaviors, pedagogical interactions, and social dynamics. It reveals motivations, perceptions, and structural subtleties, providing a depth of understanding that numbers alone cannot offer [21]. The choice to emphasize a qualitative paradigm is driven by three key methodological strengths and the contextual needs of this doctoral dissertation: a high variable-to-participant ratio, a focus on group dynamics over individual trajectories, and the ability to embrace emerging "unknown unknowns" rather than relying on quantitative reductionism.

In this educational ecosystem, the number of individual variables is too large to be fully controlled or isolated. Traditional quantitative research designs require large, standardized samples to isolate variables and achieve statistical significance [8]. Since this study is conducted in a localized setting with a specific cohort of students, a quantitative approach would lack sufficient statistical power. In contrast, in environments rich with variables, qualitative research allows the researcher to embrace complexity rather than seeking a single, universal answer applicable to every student and context [90, 21].

This dissertation does not aim to isolate and analyze individuals or fragmented behaviors, but rather to understand the group dimension and collective dynamics. Qualitative methods are well-suited to capturing how a cohort interacts, collaborates, co-constructs knowledge, and experiences the intervention as a unified learning community [90].

A strictly quantitative instrument, such as a closed-ended questionnaire, is

reductionist because it requires the researcher to predefine all possible answers and variables before fieldwork begins, limiting the study to "known-knowns" or "known-unknowns" [27]. In contrast, action research conducted in a live classroom setting is unpredictable [75]. A key strength of the qualitative approach lies in its ability to capture "unknown-unknowns", unforeseen phenomena, unexpected student reactions, and emerging themes that the researcher could not anticipate beforehand [24]. As action research cycles advance, qualitative flexibility enables the researcher to adapt, follow insights, and explore new themes in depth. If an unexpected pattern emerges during observation, qualitative tools allow exploration, while a standard questionnaire would miss or oversimplify such findings [27].

3.3 Research design and included publications

This dissertation is based on a collection of research studies conducted throughout the doctoral program. Instead of presenting standalone peer-reviewed publications in their original formats, the texts and structures of these papers have been adapted, revised, and harmonized to create a coherent narrative with logical flow.

To maintain systemic consistency, individual literature reviews and state-of-the-art sections from each paper have been extracted and unified within Chapter 2. Furthermore, in cases where more studies represent a direct evolutionary advancement of prior work, the respective papers were merged. For instance, Chapter 4 integrates two distinct papers published at different times but addressing the same research line.

While the text has been reworked to align the language, terminology, and narrative thread across the dissertation, the methodological frameworks and empirical results remain unchanged from the original peer-reviewed publications. The research design proposes two main interventions designed to answer the above mentioned research questions.

A preparatory activity for transversal competencies development via Tech Battles (Chapter 4)

The first intervention of the research introduces an exploratory research about a debate-based methodology named "Tech Battle". The development and findings of this phase were presented across two peer-reviewed papers. Designed as a preparatory and propaedeutic activity for more complex pedagogical frameworks, this intervention focuses on facilitating the engineering student's transition into active learning courses

and start developing some transversal competencies. Since Challenge-Based Learning courses demand from students several skills and professional dispositions like critical thinking, communication, and collaborative problem-solving, the Tech Battle serves to lower the initial barrier to entry, allowing students to practice essential skills and dispositions in a low-stakes environment before facing a full-scale challenge of CBL. This phase directly addresses Objective 0 and aims to answer Research Question 1.

Design, implementation and assessment of a novel Challenge-Based Learning framework (Chapters 5, 6 and 7)

The second and central intervention of this dissertation focuses on the design, implementation, and evaluation of a Challenge-Based Learning (CBL) framework centered on adaptability. This phase is presented across three interconnected chapters which were presented with three peer-reviewed papers:

Chapter 5 details the architectural setup and theoretical design of the core CBL methodology called "Choose Your Own Adventure in Challenge-Based Learning" (CYOA-CBL) framework; Chapter 6 explores the primary empirical test of the framework, conducted within a standard curricular course for Computer Science students. This test was conducted two times, with two different cohorts of students; Chapter 7 provides an exploratory and supporting evaluation of the methodology within an extra-curricular environment, offering a comparative lens on how the framework operates outside curricular constraints.

The chapters of this second phase target the fulfillment of Objectives 1, 2, and 3 while providing empirical answers to Research Questions 2 and 3.

3.4 Author's contributions

Given that this dissertation is structured as a collection of peer-reviewed articles, the original texts of which are included in the Appendix, this section clarifies my direct and specific contributions to each publication. Table 3.1 provides a summary overview of the included papers, detailing the thesis chapter in which each work was incorporated, the associated publication title, authors and venue.

Thesis chapter	**Associated publication title**	**Authors**	**Venue**
Chapter 4	Leveraging Science Fiction to Prepare Students for Tech Battles	J. Lucchetta, A. Saiani, M. Stoycheva, and L. Angeli	Proceedings of the 55th ACM Technical Symposium on Computer Science Education V. 2 (SIGCSE 2024)
Chapter 4	Revisiting Tech Battles Using Science Fiction: Methodological Implications and First Impressions	J. Lucchetta, T. Carraro, M. Stoycheva, and L. Angeli	2024 IEEE Global Engineering Education Conference (EDUCON)
Chapter 5	Choose Your Own Adventure: Empowering Students to Combine Structured and Open Challenge-Based Learning	J. Lucchetta, T. Carraro, M. Stoycheva, M. Marchese, and L. Angeli	2023 IEEE Frontiers in Education Conference (FIE)
Chapter 6	Enabling Computer Science Students to Choose Their Own Adventure in a Mandatory and Curricular Challenge-Based Learning Course	J. Lucchetta, S. Turrini, M. Stoycheva, M. Marchese, and L. Angeli	2024 IEEE Frontiers in Education Conference (FIE)
Chapter 7	Strategies for Implementing Challenge-Based Learning in Short Courses: Developing Professional Skills Through Challenges	J. Lucchetta, S. Turrini, M. Marchese, and L. Angeli	Proceedings of the 57th ACM Technical Symposium on Computer Science Education V.2 (SIGCSE TS 2026)

Table 3.1: Summary of included publications.

Paper A: Leveraging Science Fiction to Prepare Students for Tech Battles

For this paper, I co-developed the pedagogical adaptation of debate-based activities called "Tech Battles", incorporating the conceptual idea about the integration of Science Fiction short stories proposed by the co-author L. Angeli. I co-authored with equal contribution to L. Angeli the preliminary manuscript draft and designed the poster presented at the 55th ACM Technical Symposium on Computer Science Education (SIGCSE 2024) in Portland, Oregon, USA.

Paper B: Revisiting Tech Battles Using Science Fiction: Methodological Implications and First Impressions

In this paper, I collaborated with co-author L. Angeli to redesign the overall course structure based on the integration of Science Fiction short stories. Together with L. Angeli, I defined the methodology to gather data. During the Innovation & Entrepreneurship (I&E) Basics course, I supervised classroom sessions, collected qualitative field notes, and led the gathering of student self-reflections. Furthermore, I performed the qualitative analysis and wrote the main manuscript draft, incorporating feedback and guidance from co-authors.

Paper C: Choose Your Own Adventure: Empowering Students to Combine Structured and Open Challenge-Based Learning

For this paper, I conceptualized the theoretical architecture of the CYOA-CBL framework and designed its primary scaffolding mechanisms in collaboration with co-author L. Angeli. I authored the manuscript with feedback from my co-authors and presented the novel framework at the 2023 IEEE Frontiers in Education Conference (FIE) in College Station, Texas, USA.

Paper D: Enabling Computer Science Students to Choose Their Own Adventure in a Mandatory and Curricular Challenge-Based Learning Course

Within this paper, I implemented the CYOA-CBL theoretical framework into the curriculum design for the I&E Studies course, acting as a co-teacher and mentor during

classroom sessions. I designed the mixed-methods evaluation framework, managed classroom observation protocols, conducted student interviews, and executed both descriptive statistical and qualitative analyses. I authored the manuscript with input from co-authors and presented the findings at the 2024 IEEE Frontiers in Education Conference (FIE) in Washington, DC, USA.

Paper E: Strategies for Implementing Challenge-Based Learning in Short Courses: Developing Professional Skills Through Challenges

In this paper, I conceptualized and organized the short course intervention and adapted the CYOA-CBL framework for an extracurricular educational setting. I designed the mixed-methods evaluation strategy, managed observation protocols, and conducted the data analysis. Finally, I authored the manuscript with feedback from co-authors, I created the presentation poster, and presented the work at the 57th ACM Technical Symposium on Computer Science Education (SIGCSE TS 2026) in St. Louis, Missouri, USA.

3.5 Methodology of each research work

Given that this dissertation is structured as a collection of research studies conducted throughout the doctoral program, the research design of each empirical investigation incorporates distinct methodological frameworks. Each of the empirical chapters, Chapters 4, 6, and 7 is characterized by its own specific research approach, context, data collection protocols, and analytical techniques, all aligned with the objectives of the thesis mentioned above.

3.5.1 First research work: Tech Battle - Chapter 4

To address the objective 0 of this thesis and so to identify effective strategies for preparing students for Challenge-Based Learning (CBL), Chapter 4 adopts a qualitative research design centered around the pedagogical intervention "Tech Battles" mentioned above. Complex active learning environments often introduce a significant degree of discomfort, ambiguity, confusion, and cognitive dissonance for students [28]. To mitigate these potential negative effects and foster positive student attitudes toward the subsequent CBL experience, the Tech Battles intervention was designed and

implemented specifically as a propaedeutic, preparatory strategy. This qualitative approach allows for a deep, contextual understanding of how students navigate this transitional phase and how the intervention shapes their readiness for challenge-based environments. The empirical research for this study was conducted within the academic setting of the University of Trento. Specifically, the intervention was deployed within Master's degree programs in the Department of Information Engineering and Computer Science (DISI) and within EIT Double Master degree programs, with a particular focus on majors related to Digital, Urban Mobility, and Manufacturing. The study took place during the curricular course "Innovation and Entrepreneurship (I&E) Basics", a 6-ECTS course offered annually to first-year Master's students enrolled in the ICT Innovation curriculum. Data collection for this study relied on two primary qualitative sources to capture both real-time classroom dynamics and retrospective student insights. First, field observations were gathered by the research team during the course to document student engagement and interactions during the Tech Battles. Second, students completed written self-reflections at the end of the course, providing subjective accounts of their personal learning, challenges, and perceptions. To analyze the gathered data, a thematic analysis was conducted. This analytical framework allowed for the systematic coding of the data, the identification of recurring patterns, and the generation of themes regarding how the preparatory strategy influenced the students' learning experience [94, 15].

3.5.2 Second research work: CYOA-CBL in a curricular course - Chapter 6

This empirical investigation, which is presented in Chapter 6, addresses the second and third objective of this dissertation (O1 and O2): to enable students to self-adapt CBL to match their different profiles and reduce the implementation load of teaching staff in CBL initiatives. Specifically, this study tests and evaluates the conceptual work and adaptive framework designed and detailed in Chapter 5. The aim of this empirical work is to assess whether this new scaffolding is understood by students, to investigate how they use the various learning opportunities made available to them through the new scaffolding, and ultimately to determine if this adaptive approach succeeds in making the course engaging for a larger and more diverse student cohort. This study employs a mixed-methods research design and specifically, it adopts a "concurrent triangulation design" [23], which allows for the simultaneous collection and subsequent integration of quantitative and qualitative data. This design enables

the validation and cross-examination of findings from different perspectives, ensuring a robust evaluation of the adaptive framework. The study was conducted in fall 2023 and fall 2024 within the course "Innovation and Entrepreneurship Studies" (I&E Studies) at the University of Trento, a mid-sized European university. This is a 6-ECTS mandatory curricular course designed for second-year Master's students in Computer Science (CS) who are following a curriculum that integrates CS with I&E. The course runs for four months, from September to December, is delivered in English, and represents the capstone module of a minor in I&E embedded within the technical curriculum. The student population is historically heterogeneous, comprising students from double-degree programs that integrate technical competencies with business skills, including the *EIT Digital Master School*[1], *EIT Urban Mobility*[2], and *EIT Manufacturing Master Schools*[3], alongside students from pure ICT tracks and international exchange programs. While the course is embedded within a Computer Science curriculum, student backgrounds are multidisciplinary, with prior academic experience spanning fields such as Human-Computer Interaction and Design, Statistics, Mechanical Engineering, and Business Administration. In alignment with action research principles, the study was executed across two distinct iterations, allowing the research team to analyze data from the first cycle and implement iterative design improvements for the second [5]. During the first iteration, data collection relied on a combination of qualitative observations, quantitative and qualitative feedback forms, and qualitative semi-structured interviews. In accordance with the cyclical nature of action research, the insights from this initial data analysis led to specific pedagogical and structural modifications before deploying the second iteration. In the second iteration, the data collection was expanded to capture more granular student interactions; it included qualitative classroom observations, quantitative and qualitative forms, digital artifacts from Miro boards used during collaborative work, and further semi-structured interviews. Data analysis followed the concurrent triangulation strategy to synthesize the quantitative and qualitative datasets. For the quantitative data derived from student forms, descriptive statistics were performed using measures of central tendency (means, modes, medians), and standard deviations [21]. Concurrently, a qualitative thematic analysis was applied to the open-ended questions from the surveys, the transcriptions of the semi-structured interviews, field observations, and visual data extracted from the Miro boards. By triangulating these descriptive

[1] `https://masterschool.eitdigital.eu`
[2] `https://www.eiturbanmobility.eu`
[3] `https://www.eitmanufacturing.eu`

statistics with the qualitative themes, the study provides a comprehensive and multi-faceted understanding of how the adaptive scaffolding impacted student learning and engagement.

3.5.3 Third research work: CYOA-CBL in an extra curricular course - Chapter 7

The third empirical study, presented in Chapter 7, expands the evaluation of the CYOA-CBL framework by addressing three core objectives of this dissertation: making CBL adaptable to different profiles of students (O1), making CBL more manageable for the teaching staff (O2), and ensuring that CBL is replicable and flexible across diverse educational contexts (O3). While the previous chapter demonstrated the effects of the framework within a traditional, full-semester curricular environment, this study tests whether the model is sustainable and manageable for instructors when transposed into a significantly different educational setting. Furthermore, it evaluates whether the framework remains comprehensible, engaging, and open to iterative improvement when experienced by a student population distinct from the one examined in Chapter 6. This study adopts a qualitative research methodology. The context of this intervention was a four-week extracurricular activity at the University of Trento as part of an initiative promoted by the ECIU Alliance, a consortium of 13 European universities collaborating to share innovative learning activities with a dedicated focus on CBL approaches. The activity was open to Master's students from various academic disciplines, who enrolled voluntarily by submitting an application and a formal letter of intent. Worth 3 ECTS credits, the four-week program was structured with one week of intensive, in-person activities followed by three weeks conducted online. A total of 20 students from mixed academic backgrounds participated in the study, organized into four multidisciplinary teams of five members. Data collection strategies were adapted to suit the extracurricular nature of the course. To avoid overloading the voluntary participants with data-gathering instruments, the digital forms used in the curricular course were omitted. Instead, qualitative data was collected through anonymous individual feedback at the end of the course, alongside group feedback gathered after each phase of the process via short, open-ended questions embedded directly within the collaborative Miro boards. These insights were paired with teacher observations to evaluate the manageability and operational sustainability of the framework. The data analysis followed a triangulation approach across multiple qualitative methods to ensure a robust interpretation of the intervention. The thematic analysis outputs

generated from the open-ended Miro board reflections and individual feedback were integrated with the field observations recorded by the teachers. By triangulating these distinct qualitative sources, the analysis provides a preliminary understanding of how the adaptive framework performs outside a traditional semester structure, validating its flexibility for students and its manageability for educators.

3.5.4 Research timeline and summary schema

The structural and chronological progression of the empirical investigations conducted in this dissertation is mapped out across a multi-year timeline, tracking the conceptualization, execution, and analysis phases of each study from early 2023 through mid-2025 and represented in Figure 3.1.

The research began in Spring 2023 with the conceptual design of CYOA-CBL, which established the theoretical foundations of the dissertation through the conceptual development and initial design of the CYOA-CBL framework presented in Chapter 5. Following this initial step, Summer 2023 was dedicated to the re-design of "Tech Battles", focusing on the pedagogical re-design of the preparatory strategy detailed in Chapter 4. The workflow then transitioned into its first field deployment in Autumn 2023 with a phase of empirical testing, which involved the simultaneous deployment of CYOA-CBL Iteration 1 (presented in Chapter 6) and the testing of the re-designed Tech Battles (Chapter 4). The year 2024 opened with a phase of evaluation and analysis during the Spring semester. This period involved conducting post-course interviews for CYOA-CBL Iteration 1, alongside a data analysis for both CYOA-CBL Iteration 1 and the Tech Battles re-design. The empirical findings from this cycle directly informed the iterative refinement phase in Summer 2024, which was dedicated to developing iterative design improvements for the second test of CYOA-CBL. These refinements culminated in another round of empirical testing (2) during Autumn 2024, characterized by the dual deployment of CYOA-CBL Iteration 2 (Chapter 6) and the parallel testing of the CYOA-CBL framework adapted into an extracurricular context (Chapter 7). The final stages of the research timeline focused on the post-intervention assessment of the secondary cycles. In Spring 2025, the evaluation and analysis (2) phase of the multi-iteration research process was performed, encompassing the post-course interviews and mixed-methods data analysis specifically for CYOA-CBL Iteration 2 (Chapter 6). Finally, in Summer 2025, the evaluation and analysis (3) phase was dedicated to the qualitative data analysis and cross-method triangulation for the CYOA-CBL extracurricular context study detailed in Chapter 7.

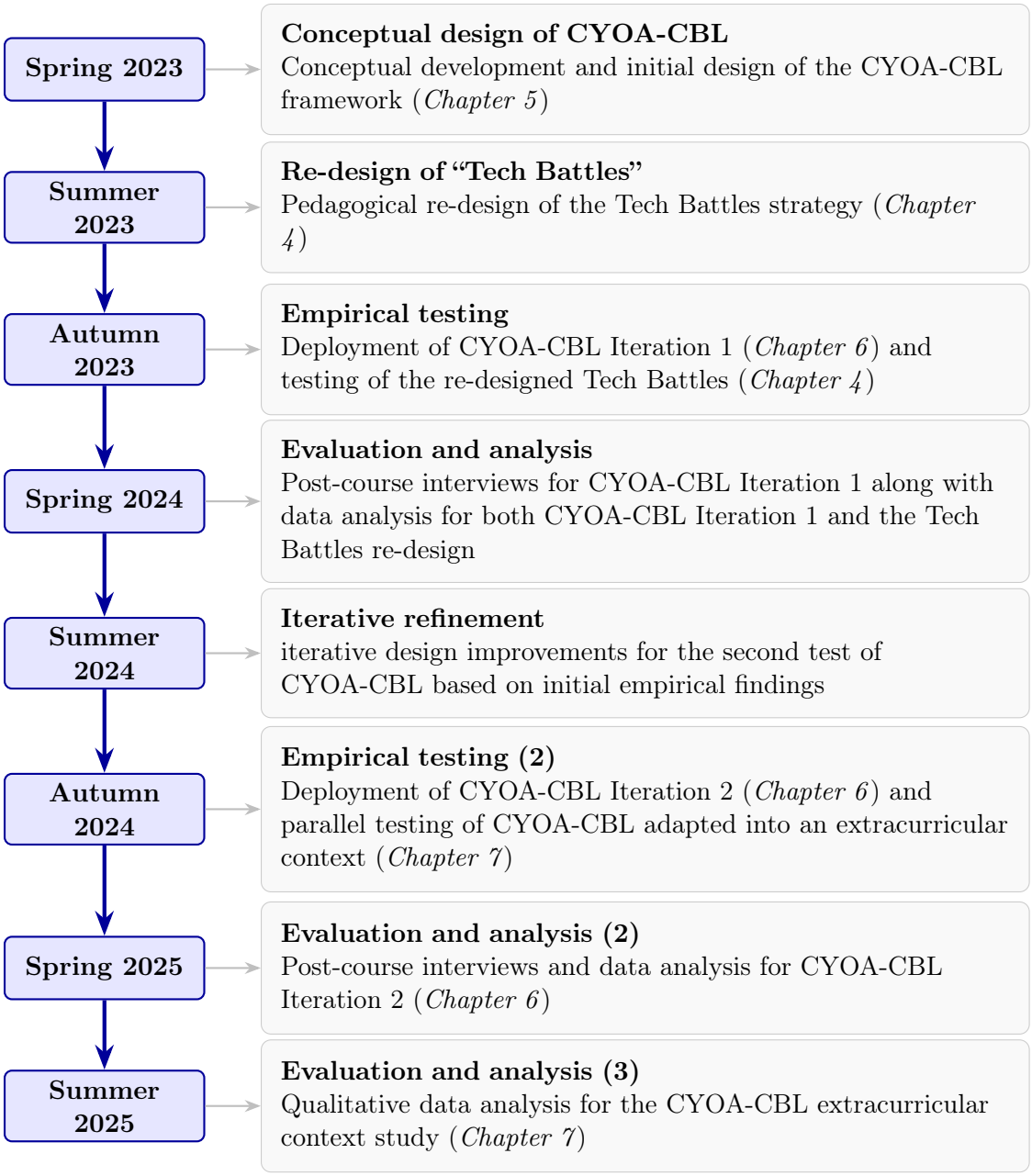


Figure 3.1: Chronological research workflow and mapping of the dissertation studies (2023–2025).

3.6 Scientific rigor and reflections

Evaluating the quality and scientific rigor of a study using qualitative and mixed-methods approaches requires moving away from traditional positivistic criteria such as statistical generalizability and absolute objectivity. Because this dissertation investigates the dynamic and highly contextualized deployment of an adaptive learning framework, its value lies in its depth of insight, procedural transparency, and iterative, reflective execution. The primary objective of this doctoral work is not to uncover universal pedagogical laws; instead, this research is intentionally exploratory, seeking to methodically map out an emergent problem space: how to make Challenge-Based Learning (CBL) more adaptable for diverse cohorts of students, manageable for educators and adaptable to different contexts. By framing these investigations in line with the action research principles, the focus shifts from a definitive evaluation to a formative understanding of a novel scaffolding design. The contribution of this work does not stem from statistical proof, but rather from the heuristic value of testing innovative teaching methodologies in classrooms, identifying what fails, understanding why it succeeds, and providing actionable insights for future implementations.

To ensure methodological soundness, trustworthiness, and ethical integrity, this section details the frameworks applied across five key dimensions: validity and transferability, reliability and auditability, reflexivity and researcher positionality, ethical considerations, and supporting digital tools.

3.6.1 Validity and transferability

To establish internal validity, the research design relies on the cyclical nature of action research and data triangulation [5, 23]. Rather than relying on a single, static snapshot of a course, the use of two consecutive iterations in the main study established a continuous feedback loop where empirical data from the first cycle directly informed structural and pedagogical improvements in the second as proposed by action research principles [5]. This iterative design validated whether conceptual adjustments successfully resolved student friction points identified in the classroom settings. Furthermore, credibility is reinforced across the empirical studies through a concurrent triangulation design. By converging distinct data streams, the findings avoid relying on a single subjective perspective. When quantitative trends in descriptive statistics align with qualitative themes extracted from student self-reflections, artifacts, and interview transcripts, potential observer bias is mitigated.

A fundamental limitation of this research is in its strict boundary within the specific academic context where the interventions occurred. The empirical data was collected primarily within the Master's degree programs of the Department of Information Engineering and Computer Science (DISI) at the University of Trento, involving international, double-degree computer science and ICT innovation students. Even the third study, which expanded into an extracurricular format under the ECIU Alliance, maintained a participant cohort of highly motivated volunteers. Consequently, the findings cannot be directly generalized to different disciplines, undergraduate populations, or institutions with fundamentally different structural resources. Recognizing this contextual boundary, this dissertation prioritizes transferability over generalizability. By providing a comprehensive and deep description of the institutional setting, course parameters, student profiles, and scaffolding mechanisms of the CYOA-CBL framework, other educators and researchers are equipped with the contextual details necessary to evaluate how these insights can be adapted to their own unique educational ecosystems.

3.6.2 Reliability and analytical audit trail

Reliability in qualitative and mixed-methods research refers to the consistency, dependability, and procedural auditability of the research process. To ensure that analytical procedures are transparent, dependable, and free from arbitrary individual interpretation, this research established a systematic audit trail alongside peer-validation protocols.

The audit trail documents every phase of the data, preserving raw data logs, anonymized interview transcripts, Miro board export archives, codes and themes. To guarantee reliability and mitigate individual subjective bias, thematic coding schemes were not developed in isolation. The qualitative data analysis was conducted through an iterative validation process involving co-authors and senior supervisors. Discrepancies regarding code definitions or thematic categorizations were critically discussed until a complete analytical consensus was achieved, ensuring that the final qualitative themes accurately and dependably reflect the underlying empirical data.

3.6.3 Reflexivity and researcher positionality

A fundamental requirement in action research is acknowledging researcher positionality, which entails how the researcher's background, professional roles, and physical presence in the field influence data collection, classroom interactions, and analytical

interpretations [5]. In this dissertation, particularly during the empirical study presented in Chapter 6, I (the PhD candidate) occupied a dual insider role, acting simultaneously as a primary educational researcher and as a co-teacher and mentor within the classroom.

While this insider positionality provided unique pedagogical access, rich contextual awareness, and the ability to capture nuanced classroom dynamics in real time, it also introduced potential observer bias and perceived power dynamics between the teacher-researcher and the students. Specifically, students might feel implicitly pressured to provide favorable feedback or modify their self-reflections if they perceive that their responses could influence their academic evaluation. To mitigate these risks and maintain critical reflexivity, several procedural safeguards were integrated into the research design. Research data collected through surveys during the course were always anonymized, ensuring that neither the researcher nor the teacher could link responses to individual students. Furthermore, semi-structured interviews were scheduled and conducted exclusively after final course evaluations and official grade submissions were completed, thereby eliminating any perceived academic dependency.

3.6.4 Ethical considerations and data privacy

Because this doctoral research involved gathering direct qualitative and quantitative primary data from human participants ethical principles were maintained across all research cycles.

Under local regulations, every study must undergo an ethics self-assessment to determine whether a formal opinion from the university's ethics review board is required. The self-assessment for these studies confirmed that data protection procedures were sufficient, and no formal ethics review was needed.

Prior to any data gathering, formal informed consent protocols were implemented. Students received detailed information sheets outlining the purpose of the study, the nature of the data collected, and the explicit guarantee that participation was entirely voluntary. Participants retained the full right to decline participation or withdraw their data at any point without incurring any penalty or impact on their academic standing. In full compliance with European data protection regulations (GDPR), strict privacy and data security measures were enforced. All audio recordings of semi-structured interviews were transcribed and immediately anonymized by stripping personal identifiers, direct names, and sensitive contextual details. Digital artifacts exported from Miro boards, survey spreadsheets, and transcript files were stored

securely on university folders. Furthermore, participants were assigned unique numeric identifiers across all datasets, analytical records, and dissertation excerpts to guarantee confidentiality.

3.6.5 Digital tools and analytical software

To maintain data organization, analytical rigor, and collaborative learning execution, specific software platforms were used across the research workflow. During the second research study (Chapter 6), *Miro* served as the primary digital collaboration workspace for interactive real-time process scaffolding. Beyond its pedagogical function, *Miro* enabled non-intrusive data collection by allowing researchers to export visual artifacts and embedded qualitative student workflows.

For the qualitative analysis of interview transcripts (Chapter 6), audio recordings were transcribed using *Whisper*, executed locally to minimize data exfiltration risks and safeguard participant privacy. Finally, *NVivo* enabled structured data management, systematic text segment coding, and the hierarchical organization of parent and child nodes during thematic synthesis.

Chapter 4

Leveraging Tech Battles to prepare students for transversal competencies

This chapter introduces the first practical intervention of the research: the "Tech Battles".

As highlighted in Chapter 2, the transition from traditional, passive education to complex, open-ended methodologies like CBL represents a significant shift for students [38]. This shift often demands a level of autonomy, critical thinking, and communication skills that students may not have yet fully developed.

Before addressing the complexity of CBL implementations, it is useful to explore how other active learning techniques can be used to prepare Computer Science (CS) students to develop these transversal competencies. It is crucial to ensure they face environments such as CBL with the right attitude and disposition to manage uncertainty, ambiguity, and collaboration.

In this context, the "Tech Battles" are proposed to addresses the objective "zero" (O0) of this dissertation - find strategies to prepare students for Challenge-Based Learning (CBL) as propaedeutic active learning activity. Tech Battles aim to provide a "training ground" where students can exercise essential transversal competencies, specifically public speaking, argumentation, and multi-perspective analysis, before applying them in the high-stakes but still protected environment, such as a CBL course where students must deal not only with their group members but also with external actors who act as challenge providers, mentors, and teachers.

The study presented below maximize the effectiveness of a debate-based methodology, by integrating Science Fiction narratives as a strategic enabler. By grounding debates in scenarios designed starting from Science Fiction short stories,

rather than current technical specifications, the activity neutralizes the anxiety of "not knowing enough" technical details. This allows CS students to focus entirely on the logic of argumentation and the dynamics of the debate, creating a leveled playing field where the emphasis is placed on the process of arguing rather than the correctness of the technical facts.

This initial intervention:

- introduces a structured active learning intervention, named Tech Battles, with the aim of developing transversal competencies and prepare students for a CBL course;
- shows how to engage students in a safe, decontextualized environment to prepare them to handle the complexity and ambiguity they will encounter in real-world CBL challenges;
- uses Science Fiction narratives as a possible tool to lower barriers to entry for students, increasing engagement and reducing the fear of judgment.

The content presented in this chapter is a minor adaptation of the following peer-reviewed publications:

- **Revisiting Tech Battles Using Science Fiction: Methodological Implications and First Impressions**
  J. Lucchetta, T. Carraro, M. Stoycheva, and L. Angeli
  Published in 2024 IEEE Global Engineering Education Conference (EDUCON), Kos Island, Greece, 2024, pp. 1-5, doi: 10.1109/EDUCON60312.2024.10578814.
- **Leveraging Science Fiction to Prepare Students for Tech Battles**
  J. Lucchetta, A. Saiani, M. Stoycheva, and L. Angeli
  Published in Proceedings of the 55th ACM Technical Symposium on Computer Science Education V. 2 (SIGCSE 2024). Association for Computing Machinery, New York, NY, USA, 1728–1729, doi: 10.1145/3626253.3635532.

The following sections detail the methodological design of the Tech Battles, the specific implementation of the Science Fiction scenarios, and the empirical results regarding CS student skill perception. The chapter starts with Section 4.1 describing the context where our intervention takes place; Section 4.2 details our methodological upgrades and the criteria for selection of the Science Fiction short stories; Section 4.3 presents the new workflow with an example; Section 4.4 presents some preliminary

results and discussions based on our field observations, and Section 4.5 brings back the conclusions to the RQ1 and O0 of the dissertation, outlines our plans for future work and broader reflections.

4.1 Pedagogical context and gap

In the last decades, the highest academic aggregators in computing (such as the ACM and IEEE) have acknowledged the growing importance of developing non-technical competencies in computing curricula. To cultivate skills and dispositions, universities are shifting towards active learning methods, among which debate-based classes are a notable case. Such transversal competencies form an important part of what is expected of computing professionals in the industry, and are frequently developed — though implicitly — in computing curricula through courses in Innovation and Entrepreneurship (I&E) [109, 7]. While previous literature showed that debates are used across various knowledge domains [14] to foster transversal competencies such as information synthesis, critical thinking, and effective verbal communication [45], their integration into computing education is still rare.

Our intervention addresses this gap within a course called "Innovation and Entrepreneurship (I&E) Basics", which has been taught since 2013 at the University of Trento. This 6-ECTS course is offered annually to first-year Master's students in a Computer Science curriculum called ICT Innovation which combines CS with innovation and entrepreneurship. The course is curricular and mandatory and it teaches the basics of innovation theory, entrepreneurial practice, and the social impact of computing, while developing skills and dispositions [40] such as oral communication, clear presentation and critical thinking. Here, students take I&E Basics as the first step in a 30-ECTS "minor degree in I&E" while specialising in a technical subdomain such as Cybersecurity, Autonomous Systems, or AI innovation, among others. Class sizes have varied significantly over the years, ranging from as few as 20 students to as many as 180. Since 2020, enrollment has stabilized, and the class size is typically around 40 students.

Since 2013, the teaching team adopted a debates-based teaching method, called "Tech Battles (Battles)", where two teams of 4–5 students debate opposed views on a socio-technical theme in the domain of technological innovation. Since their first appearance, Battles have evolved through several iterations developed by our research group. Early works described the shift from historical case studies to fictional scenarios [12], while subsequent studies introduced a more structured approach to meet

student needs [4].

Each Battle is structured in three main phases:

1. **Battle Preparation:** A 1-hour meeting, done outside class time, two weeks before the Battle. The two teams and the teachers create the scenario and define what points the teams should debate about. Scenarios aim to build plausible alternative worlds that combines real-world and fictional elements set around a key central tension and where the class can have a discussion free from their own prejudices [58].

2. **The Battle:** A 2-hour class slot where teams debate and the class acts as an active audience, asking questions and ultimately voting for the more plausible proposal.

3. **Battle Report:** A document delivered at the end of the course, in which the two teams synthesize the knowledge acquired through the process and reconcile their positions.

The course and its methodology follow a practice of continuous improvement and innovation, where we continually assess how to adapt our teaching to a constantly-changing world. Despite the success of this format, the previous structure presented key weaknesses for both students and teachers. Firstly, students arrived at the Battle preparation meeting without prior knowledge of the debate topic. Our previous observations indicated that students found it demanding to quickly comprehend the direction of the Battle while simultaneously navigating the scenario. This lack of context made it difficult for them to quickly comprehend the direction of the Battle or contribute meaningfully to the scenario creation. Secondly, the creation of scenarios relied entirely on the teachers' creativity. The choice of debate topic is a particularly controversial theme, since it can influence the students' motivation, experience, and understanding of the course's content. This imaginative task – building plausible alternative worlds free from prejudices – places a significant burden on the teaching team, potentially hindering the replicability of the method. This imaginative task is repeated for each Battle in a course, and teachers need to consistently tap into their creativity. While this has not been a problem for us so far, we recognise that creativity might be an individual competence, and simplifying the teachers' task could enhance the method's replicability.

To address these challenges, we propose a further evolution of the Tech Battles methodology that introduces the reading assigned by the teachers of Science Fiction

(SF) short stories as a preparatory activity. This pedagogical choice is grounded in similar pedagogical studies and initiatives described in Chapter 2, which highlight the potential of Science Fiction as a powerful tool to help engineering students envision the societal integration and ethical implications of technology.

The following sections explore a partial redesign of the Tech Battles and we discuss how this latest modification changes the course and its impacts: our criteria for selecting short stories, how the workflow of each debate evolved, preliminary observations gathered from the field, and the research methods that will be used to more thoroughly validate the updated method.

4.2 The redesign: integrating Science Fiction

With this redesign, we propose to enhance student readiness for the Battle preparation meeting through a Science Fiction (SF) short-story reading activity. As discussed in Chapter 2, suitable stories can help students develop a critical view of technology, broaden their imagination, and introduce key themes and opposing viewpoints for their Battle. These narratives serve as a starting point for teachers to create scenarios, framing Battles as genuine controversies and streamlining the process of scenario generation. We selected Science Fiction due to its long-standing literary tradition of exploring ethical and societal dilemmas using scientific and technological metaphors. As noted by Haraway [46], SF possesses a unique power for critique and it has been used to create academic syllabi such as *Speculating Futures*[1]. The stories we adopt in the course explicitly feature critiques to innovation, progress, or specific pieces of technology, since they provide the key benefit of being easy to connect to contemporary technological controversies, such as privacy and AI, and their ease in creating grounds to generate scenarios for debates [61].

Suitable short stories can introduce students to the themes they will address during their Battle with a modest time investment and to ensure an easy comprehension in a short span of time. By choosing relevant stories, teachers can "prime" the students' imagination, stimulate their curiosity, and enroll them in co-creating the scenario.

For this reason, with this redesign, we now assign student teams a short story three weeks before their Battle. The ensuing Battle preparation meeting starts by discussing the short story, and then proceeds by co-creating the scenario. With this adaptation, scenario building can now see a more active contribution of the students

[1]See `https://github.com/frnsys/speculating_futures` (last access 2025/12/15).

because, through the short story, they can better grasp the scenario's pedagogical intent. As an example, students can give feedback and help the process of generating the debate positions based on the tensions they found in the short story. The meeting then finishes as per our normal model, with teams being assigned to one of the two positions.

4.2.1 Criteria for story selection

However, we asked ourselves how a teacher should select Science Fiction short stories: should they remain the same across the years, or should they change? In the first edition of the course, we pre-selected short stories from our own reading experience. If stories could change over the years, though, should we create a systematic selection procedure, for example using stories from collections that won literary prizes? Another alternative could be instead to base our selection on literature discussing reading Science Fiction as a curricular activity. Could we, for example, imagine a partnership between our I&E Basics course and courses such as Speculating Futures, where the latter proposes short stories and commentary, and the former uses them for debating? And, if so, how could we contribute back?

The teachers' crucial task is now that of selecting appropriate stories that can foster critical perspectives on innovation, progress, and technological advancements, sparking thought-provoking discussions on timely technological debates like mentioned before.

To ensure the readings are effective within the constraints of the course, we established the following selection criteria:

- **Technological controversy:** the story must feature a technology or technological problem that creates controversies linked to a socio-ethical concern.

- **Critical perspective:** it must offer a fair, critical perspective concerning the technology.

- **Conciseness:** the text should allow students to complete the reading within roughly one hour.

- **Relevance:** the overall topic must have a clear connection to mainstream contemporary technological debates (e.g., privacy, AI).

4.3 The updated workflow

The Tech Battles teaching method is in constant evolution but, over the last few years, we have made some fundamental changes, which are now illustrated by discussing in detail our four-phase workflow showed in Figure 4.1.



Figure 4.1: The general workflow of each Battle, that each pair of teams of students follow.

4.3.1 Phase 1: Preparatory Reading

Student, who are grouped in teams and assigned to a debate in the first lessons, receive a short story three weeks before their Battle. They are given one week to read the story, understand the narrative, and reflect on its main themes. This ensures that when they arrive at the preparation meeting, they already possess a shared understanding of the ethical and societal contradictions at play.

4.3.2 Phase 2: Battle Preparation

Two weeks before each debate, students and teachers participate in the Battle Preparation, a one-hour meeting where the participants collectively decide the goals and boundaries of the upcoming Battle in a spirit of joint creation.

The Battle Preparation is structured in several phases described in Figure 4.2. These include:

- Summary and alignment: the meeting starts with the teacher asking the students to give a concise summary of the reading, emphasizing key points in the narrative, to establish a shared understanding among the participants. A key step during this phase is to ensure that everyone shares an understanding of the ethical and societal contradictions that appear in the story to lay the foundation for discussion.

- Scenario co-creation: once the alignment is reached, teachers propose a scenario based on the story's controversy, and defines short labels that define the two

positions that will face each other in the debate. Students give feedback and help generate the debate positions based on the narrative's tensions.

- Defining the Battle: after the two positions are defined, teachers and students collaborate to improve the scenario if needed, and create a clear list of elements that each team must incorporate into their "opening statements" presentations. Defining these elements establishes a common ground for the Battle, ensuring that the two opening statements align with the central tension, and that the two teams have opposing views on the same sub-themes.
- Assignment: at the end of the Battle Preparation, the teams decide which of the two opposite positions they want to take or, if they are undecided, they are randomly assigned to a position.

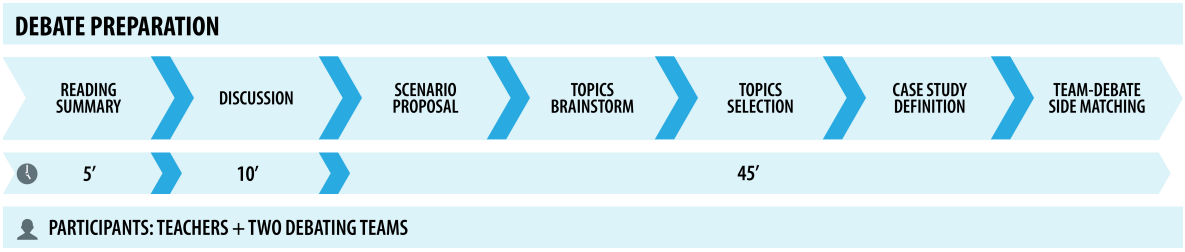


Figure 4.2: The structure and sub-phases of the Battle Preparation meeting.

4.3.3 Phase 3: The Battle

The Battle takes place in a regular two-hour class slot. The teacher introduces the scenario to the audience. The core phases of the Battle, which are unchanged from our previous design, consist of "opening statements" presentation from each team, two rounds of open debating, and "closing statements".

The Reflective Phase:

A significant addition to the redesign is the specific structure of the feedback session. As we stated in our previous contributions, the teaching team has to keep the role of an impartial moderator. This impartiality is fundamental to create a fair debating (and learning) environment, but it has in the past prevented teachers from calling out content mistakes made by students in the name of balance. For this reason, we now include in each class a reflective phase, divided between "course corrections" and "technical suggestions":

- Course corrections: teachers point out content mistakes made during the presentation. This allows for factual correction or short points of feedback connected to each presentation's content without disrupting the flow of the debate.
- Technical suggestions: teachers focus on practical suggestions regarding language, delivery, and presentation design to help students improve their work and public speaking skills.

This adjustment enables the teaching team to effectively fulfill their roles as both moderators and content holders.

As a minor change from our previous model, both teams are now evaluated equally (unless one team was radically better prepared than the other), encouraging students to view the Battle as a collaborative performance rather than a zero-sum game.

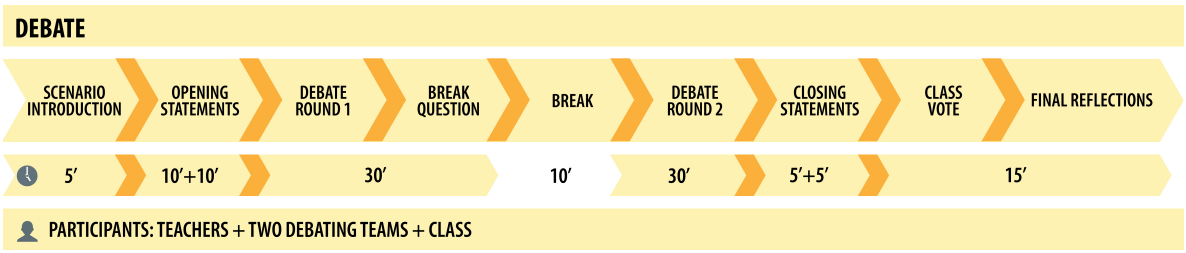


Figure 4.3: The structure and sub-phases of the Battle itself.

4.3.4 Phase 4: Battle Report

The final phase, the "Battle Report", is unchanged from our previous work. After the end of the course, the two teams jointly write a short report synthesizing the insights gained during the Battle and reconciling the two opposing positions.

4.3.5 Battle workflow example

As an example of our updated model, we briefly present here the full flow of a Battle, from reading to report:

Reading

Three weeks before their Battle, students received a reading: "The Truth of Fact, The Truth of Feeling" by Ted Chiang [20]. In the short story's two sub-plots, the main characters deal with issues of trust and truthfulness, driven by the introduction of technologies that reshape their definitions of privacy and transparency.

Scenario

We created a scenario where the ocular camera featured in one of the story's sub-plots (and its annexed publicly-searchable audio/video archive) is a reality. The request for the teams of students will be to develop alternate value propositions, and different world views, based on the same technology: one where every video captured by the camera is openly accessible to everyone (the "transparency world"), and one where individuals have complete control over their videos they record (the "privacy world").

Battle preparation

The teams and teachers summarised the story, then reflected together on the two views, ultimately agreeing on four main points that the opening statements presentations should contain: (1) how each world broadly looks like; (2) how their world deals with crime; (3) how journalists operate in their world; (4) their world's "killer app" — justifying why most people decided to adopt the ocular camera. The preparation meeting closed with each team being assigned to one side.

Battle

The two teams presented their positions: the "privacy world" focused on data protection and authentication, empowering individuals to choose who gets access to data, and leveraging this to safeguard whistleblowers; the "transparency world" proposed a world where incentives for crime are drastically reduced and greater research/industrial collaboration, with competitions limited to challenges of skill rather than information asymmetry.

Report

The two teams reconciled their views in their Battle Report, ultimately proposing a third view that takes into account what happened in the Battle, providing their reconciliating "fair tale" [59].

4.4 Implementation and preliminary results

In the Academic Year 2023/24, we implemented this redesign with 31 attending students, forming 8 groups for 4 Battles.

We selected stories primarily from Ted Chiang's collection *Exhalation* [20] and Ursula Le Guin's *The Unreal and the Real* [60]:

- **"The Lifecycle of Software Objects" (Chiang):** led to discussions on the implications of virtual life.
- **"Dacey's Patent Automatic Nanny" (Chiang):** formed the basis for a Battle on AI in digitized education.
- **"The Ones Who Walk Away from Omelas" (Le Guin):** revolved around the uneven benefits of technological development.
- **"The Truth of Fact, The Truth of Feeling" (Chiang):** used for a debate on privacy vs. transparency.

From our anecdotal experience and preliminary looks at the students' end-of-course self-reflections, we have observed several promising trends and a generally high understanding of their debates. In the past, students faced challenges in understanding the overarching topic of their Battle and its connection to the scenario. The use of the short stories to construct scenarios has facilitated a deeper understanding among students. This addition helped enhancing the learning experience, but also addresses conceptual gaps that students may encounter with complex topics and scenarios. The short stories greatly helped in focusing preparation meetings, making it easier to introduce the central tension of each Battle. By selecting short stories covering themes that are connected to current events, students quickly grasped the relevance of the story and the debate in general. The "course correction", finally, cemented each Battle as a learning opportunity for the whole class, consolidating the teaching team as both moderators and content facilitators.

Even in our limited experience, not all Battles were successful. One, in particular, had to be rescheduled: while students had clearly understood the central tension of their Battle, the two teams had different understandings of what they needed to include in their opening statements, leading to too little common ground for a fruitful debate. This unsuccessful Battle highlights that, while we see an improvement in our methodology, it is still not trivial to understand for students, who can face difficulties in creating presentations for a solid debate.

Language barriers posed another challenge for students. The course is taught in English, and in this particular year uneven language proficiency often made students find themselves struggling to articulate their arguments effectively.

An undoubtedly positive note has been that with this cohort we observed more interactive Battles, highly involving the teams and the audience. In our previous iteration, the students themselves explained the scenario to the class, while the teacher now introduces the scenario, resulting in an audience with a clearer understanding — which is ultimately more engaged and active, posing numerous questions and providing a stimulating environment for the debate.

The introduction of the final reflections has also been a positive addition. As Battles passed, teachers made fewer and fewer observations, particularly regarding technical suggestions, as students integrated the corrections provided in previous debates.

4.5 Conclusions

This chapter presented the redesign of the Tech Battles teaching method, illustrating how a debate-based active learning framework integrated with Science Fiction (SF) narratives can prepare Computer Science (CS) students for complex educational environments. Below, we summarize how this intervention directly addresses the primary objective of this phase (O0) and answers Research Question 1 (RQ1).

Objective 0 of this dissertation sought strategies to serve as a propaedeutic activity to prepare students for Challenge-Based Learning (CBL) and foster transversal competencies. Tech Battles act as a low-stakes "training ground": by exercising core transversal competencies — public speaking, structured argumentation, and multi-perspective analysis — within a controlled classroom setting, students build the necessary cognitive dispositions to navigate the ambiguity, uncertainty, and multi-stakeholder collaboration required by a CBL course.

Based on our design and field observations, this chapter contributes the following insights to RQ1: the redesign of the debate-based methodology called Tech Battles, anchored in Science Fiction short story scenarios, suggests potential for mitigating learning resistance. The integration of SF short stories grounds technological controversies in fictional, decontextualized settings rather than immediate technical specifications. This design choice helps alleviate student anxiety, remove the fear of judgment, and lower barriers to entry. Additionally, it fosters confidence in transversal competencies, cultivated through structured scaffolding and the co-creation of scenarios during preparation. The introduction of the *Reflective Phase* provides immediate, actionable coaching. As observed across debate iterations, students systematically integrated teacher suggestions, demonstrating increased confidence and fluency in public speaking and audience engagement.

4.5.1 Limitations and future work

While preliminary observations and student end-of-course self-reflections demonstrate positive engagement and enhanced conceptual clarity, formal empirical validation remains a future step.

Additionally, a further line of inquiry concerns the selection of stories. Currently, stories are pre-selected based on the teachers' reading experience. The short stories also aided new members of our teaching team in grasping the general Battles methodology and scenario creation. Further investigation should go towards making Battles even more replicable outside our context, potentially through the creation of implementation guidebooks. Ongoing work includes a comprehensive mixed-method analysis of anonymous student surveys, comparing results to previous implementations when relevant. Future iterations might explore systematic selection procedures (e.g., award-winning collections) or partnerships with literature courses, such as *Speculating Futures*, where one course produces the commentary and the other uses it for debating.

4.5.2 Reflection on Computing Education

In closing, we propose a reflection about the intersection of Science Fiction with computing education. Research in Futures Studies recently argued that we are crossing times of "imagination crisis", where we individually and collectively struggle to imagine positive futures [115]. As mentioned in Chapter 2, the Science Fiction read by engineering students are sometimes linked with what technologies those engineers will create [53]. If technologies are socially constructed objects, and we wish to orient technology for planetary good, we ought to reflect more deeply on where technology is first envisioned. Computing educators have the opportunity to claim a stronger role in shaping the future technologists' imaginations, and in guiding them to see technology creation as a responsible act.

Chapter 5

Choose Your Own Adventure: empowering students to combine structured and open Challenge-Based Learning

Having established the importance of preparatory "training grounds" in Chapter 4, this chapter moves the focus to the core pedagogical intervention of this dissertation: the implementation of Challenge-Based Learning (CBL) itself.

As discussed in Chapter 2, in a CBL course, students must develop and apply transversal competencies to solve open and real-world problems. However, deploying CBL in mandatory engineering curricula introduces a critical design paradox. As mentioned before, purely *open* CBL approaches reflect the true "wickedness" of real-world problems but often lead to chaos, student anxiety, and unmanageable workloads for teachers. Conversely, highly structured CBL approaches provide safety and ease of assessment but risk sterilizing the learning process, turning a creative challenge into a linear exercise that fails to stimulate autonomy [11].

This chapter addresses this tension by introducing our novel framework named "Choose Your Own Adventure in Challenge-Based Learning" (CYOA-CBL).

Within the broader methodology of this dissertation, CYOA-CBL is proposed as a tool to fulfill Objectives 1, 2, 3, and offering a possible strategy to overcome the three identified barriers that currently hinder the widespread adoption of CBL in computing education. CYOA-CBL aims to be adaptable to different profiles of students, be more manageable by teaching staff and replicable and flexible in different context of

higher education. It is designed to provide the authenticity of real-world challenges while ensuring a robust, adaptable scaffold that prevents the experience from becoming overwhelming for students. In this chapter, the focus is on the possibility of shifting the trade-off between structure and openness from a static design choice made by the teacher to a dynamic choice made by the students.

The content presented in this chapter details a conceptual study and the theoretical design of the CYOA-CBL framework and is based on the following publication:

- **Choose Your Own Adventure: Empowering Students to Combine Structured and Open Challenge-Based Learning**
  J. Lucchetta, T. Carraro, M. Stoycheva, M. Marchese, and L. Angeli
  Published in 2023 IEEE Frontiers in Education Conference (FIE), College Station, TX, USA, 2023, pp. 1-5, doi: 10.1109/FIE58773.2023.10343390.

The following sections present the theoretical basis of the framework and its "Paths and Phases" design, illustrating how the model empowers students to have more autonomy. This chapter will proceed in the following way: Section 5.1 will give the motivation behind this work; Section 5.2 will go more in depth on the proposal, explaining the CYOA-CBL structure, as well as giving an example of a complete path, and of alternative approaches to an individual phase; Section 5.3, will provide some points of reflection and possible future work, some of them tackled in the next chapters.

5.1 Motivation and context

As previously explained in Chapter 2, the implementation of Challenge-Based Learning (CBL) in engineering education is often characterized by a tension between *structure* and *openness*. This tension was formalized by Bombaerts, Martin, and Doulougeri during the Frontiers in Education conference 2022, who observed the trade-offs inherent in these two approaches during three courses that used Challenge-Based Learning (CBL) to teach ethics to engineer [11].

In the article, they define structured CBL as a context where "[the] university [defines] what the important aspects are that have to be learned", and open CBL as one where "students [decide] for themselves how much or how little [content the course] should entail". The authors also discuss some trade-offs that ensue from both approaches: structured approaches are easier to assess, more comfortable, and favour depth; open approaches are more demanding, better reflect the wicked nature of challenges, and are more creative.

This distinction has been relevant in reflecting on one of our own CBL course, a second-year Master's course for Computer Science students, acting as the final course in a "minor in Innovation and Entrepreneurship" (I&E). This course serves as the capstone of the I&E minor and represents the direct continuation of the "I&E Basics" course discussed in Chapter 4, where the Tech Battles methodology was deployed as a preparatory step. The course, that first ran in 2017, is taken every year by 45 to 70 students, and involves 4 to 7 external stakeholders as challenge providers. The course is mandatory, and many of the involved students are part of a double degree programme called *EIT Digital Master School*[1] lately extended also to *EIT Mobility*[2] and *EIT Manufacturing Master Schools*[3]. The heterogeneity of the students is reflected in widely different levels of intrinsic motivation [6], knowledge, commitment, willingness to engage, and preference for a course that is either more structured or more open.

In this context, a rigid "one-size-fits-all" approach, whether fully open or fully structured, creates friction and in this chapter, we want to sketch our proposal to create a single teaching context that can flexibly cater to students with different wishes. As noted by Eldebo et al., CBL is inherently demanding for both students and teachers [36]: by re-positioning the structured/open trade-off from a problem of course design to a student choice, teachers can match more easily their work to the students' motivation and, we believe, can contribute address some of CBL's scaling woes.

This proposal defines a novel CBL structure to enhance the scalability of CBL by creating a process which is replicable, more manageable, and adaptable to varying student motivations and profiles.

We call this proposal "Choose Your Own Adventure in Challenge-Based Learning" (CYOA-CBL). CYOA-CBL structures the course in a sequence of "phases", and defines alternative "paths" that can be taken by the students. Students have several alternatives to tackled each phase, representing alternative ways to explore solutions to challenges, and may opt to follow a pre-defined path (a structured approach), create their own path and leverage their own knowledge (an open approach), or adopt an in-between solution.

CYOA-CBL represents, to the best of our knowledge, a novel approach, and gives two main contributions to the area of CBL in engineering education: first, it proposes to re-define Bombaerts' structured/open trade-off as a spectrum rather than as a duality; second, it aims to start a deeper reflection in how to address the matter of CBL's

[1] `https://masterschool.eitdigital.eu`
[2] `https://www.eiturbanmobility.eu`
[3] `https://www.eitmanufacturing.eu`

scalability by giving CBL courses a replicable yet flexible structure.

5.2 Our proposal

As mentioned above, students taking mandatory courses may have highly diverse motivations [6]. Consequently, the scaling of CBL, which is frequently applied to extra-curricular activities, to curricular courses cannot be fully painless: as noted by Norrman et al. [79], CBL courses are more demanding for all involved stakeholders, including staff and, most importantly, students. Many university students are already subject to stress in university settings [26]: if more courses were to adopt CBL – and thus become more demanding as per [36] – students' stress levels may increase even further.

In some ways, this tension is already present in the "structured" and "open" CBL duality: if students have highly diverse motivations, it is likely that, independently from whether teachers take a structured or open approach, their choice will be at odds with some students' motivations.

To solve this tension, we propose to look at the categories of "structured" and "open" CBL not as a dichotomy, but as two ends of a spectrum, and let students position themselves on this spectrum. This is the essence of CYOA-CBL: empowering students to adapt a CBL course to fit their motivations.

Our name, "Choose Your Own Adventure", is inspired by a series of books where readers go through a story featuring several decision points. Readers may, for example, decide if the character in the book should take the left or right path at a crossroads; the story would then evolve accordingly, with each reader experiencing a variant of a general cohesive story. Similarly, a CYOA-CBL course aims to be a cohesive experience, while letting students choose alternative paths.

5.2.1 General structure of CYOA-CBL

As with any other CBL course, CYOA-CBL foresees students divided into teams facing a challenge proposed by an external stakeholder.

Previous authors have underlined the importance of dividing the CBL process in phases to help students make sense of the process [3]. In CYOA-CBL, we foresee six phases, loosely mapped to the popular "engage/investigate/act" cycle [78]:

- **challenge identification**, where students explore the challenge proposed by the provider and delimit its scope;

- **problem space exploration and goal-setting**, where students analyse the challenge, gather information and agree on a general idea that they wish to pursue;
- **work plan definition**, where the team splits work internally, defines internal deadlines and plans the project;
- **investigation**, where students gather data to support the validity of their idea as desk research or as field work;
- **analysis**, where the team analyses the data obtained from the previous phase;
- **solution proposal(s)**, where students finalise their work into one or more possible solutions for the challenge.

For each phase, teachers prepare several packages of teaching materials (e.g. videos, tutorials, readings, etc.) and exercises, representing alternative ways to enable a form of just-in-time learning that helps students reach the goals of that specific phase. Each phase also has a common *worksheet*, a checklist that doubles as a way for students to check that they have fulfilled all the requirements for that phase and as assessment.

The specific teaching materials and exercises are different for each CYOA-CBL course, and are based on each course's angle (e.g., a course featuring many business challenges may prioritise business content; one with social challenges may prioritise social content). Open Educational Resources can help teachers create these packages efficiently, so that they can focus on mentoring the students. Worksheets, instead, are common for all courses using a CYOA-CBL structure, containing guiding questions, and checklist elements such as "have you completed the suggested exercise for this phase?".

The sequence of the six pairings between phases and specific content/exercises students used in each phase is called a "path". When implementing each CYOA-CBL course, the teacher curates some predefined paths, with activities proposed for each phase. In Figure 5.1 we give an example of a course, with three predefined paths, generically called "Path A", "Path B" and "Path C". These predefined paths give the students' work a specific flavour, such as a "business modelling" path or a "product development" path. Teams of students may freely switch between paths, or propose their own approaches to the various phases.

This flexibility gives students the possibility of having a more structured or open experience, with three options:

1. follow a predefined path proposed by the teacher;

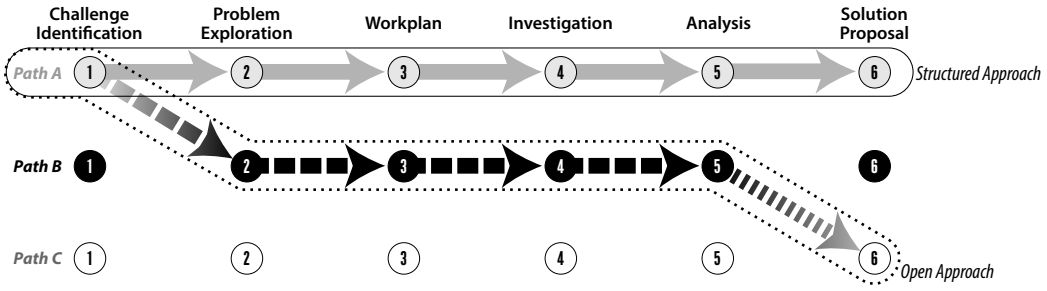


Figure 5.1: The phases-and-paths structure of a CYOA-CBL course, with two possible approaches for going through the course.

2. switch between different predefined paths on a phase-by-phase basis;

3. propose their own activities for some (or all) phases.

These three options create a spectrum that goes from fully structured CBL to a much more open experience. Again in Figure 5.1, we give an example of a team of students choosing a structured approach (linearly following Path A), and a more open approach (switching from Path A, to B, and then C).

To illustrate the framework in practice, we present in more detail a whole predefined path and some alternative options that may be used in a phase.

5.2.2 Worked example: the "Scenario Modelling" path

The CYOA-CBL framework was developed for a course where challenges usually come from startups and early-stage business ideas. These often require exploring potential directions for the providers.

For this reason, the proposed example is a "Scenario Modelling" path, whose goal is to examine a range of potential futures for the challenge provider, and outline plausible solutions. For this path, the teacher provides the students with these activities for each phase, summarised also in Figure 5.2:

- **Challenge identification**: students perform a mission definition activity, for example using the Business Model Canvas [80]. Through this exercise, students get a better understanding of the provider's context, and identify potential areas of intervention.

- **Problem space exploration and goal-setting**: during this phase, students investigate external factors that influence organisations such as the provider.

Through the "11 Sources of Disruption" exercise[4] students explore the state of the art and new innovations in the provider's industry, and determine the essential aspects that impact the challenge. To close this stage, students create a loose list of potential scenarios they want to explore.

- **Work plan definition**: in this phase, students decide more precisely the direction their work will take, creating a plan to manage their project. Teachers may run, here, a workshop on how to divide responsibilities and workloads, using simplified Gantt charts to develop a roadmap with goals and milestones.

- **Investigation**: students work on scenario creation, using for example the "Three Horizons Framework" [100], and find evidence to support these scenarios through research on online databases such as Statista[5] or the United Nations Open Data website[6], or perform field work using Strategic Interviews [88].

- **Analysis**: to validate proposed scenarios, students use exercises such as the First Mover Advantage [62] to analyse their work critically. The phase also includes a short reflection step where students check whether the scenarios they developed fit with the goals and constraints identified by the students in the previous phases.

- **Solution proposal**: in the last phase, students use frameworks such as the Preferred Future Canvas[7] to argue what the most likely scenario could be, and produce a deliverable that will be assessed by the course' teachers. The final deliverable can be a written document, but also a presentation, or other forms such as infographics [8].

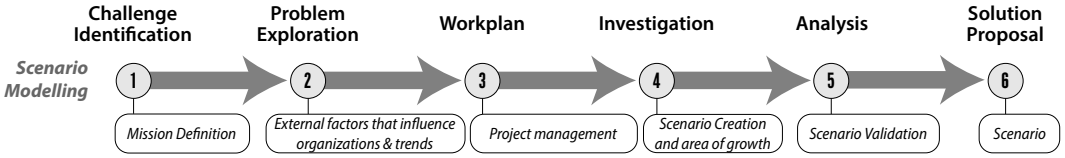


Figure 5.2: A "Scenario Modelling" path, with potential exercises defined for each of the six phases.

[4] https://sloanreview.mit.edu/article/the-11-sources-of-disruption-every-company-must-monitor/
[5] https://www.statista.com
[6] https://data.un.org
[7] https://futuresframework.com/preferred-future-canvas/
[8] https://docs.google.com/document/d/1MikaQXHhXvmOmUU1kPwcLW6Ofrod6qBIII6ZmOyxJ2c

5.2.3 Worked example: alternatives for the investigation phase

The second example further explores the Investigation phase, and proposes possible alternatives for its completion, which we also present in Figure 5.3.

To complete the investigation phase, teams may:

- work on scenario creation using the Three Horizons framework, in a scenario modeling path;
- define one or more target audiences using the buyer-persona template[9] and interview the selected segments, if they're following a customer-product fit path;
- perform a competitor analysis using the Volatility, Uncertainty, Complexity & Ambiguity framework[10], if they're following a market analysis path;
- design a solution concept through The Open Group Architecture framework[11], as an open path.

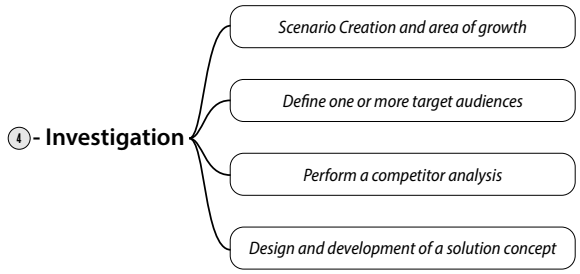


Figure 5.3: Potential alternative approaches to the investigation phase.

5.3 Conclusions

The design of CYOA-CBL is intended to address the limitations of current CBL implementations regarding the three barriers to adoption identified in Chapter 2—namely *student readiness and motivation*, *necessary resources and scalability*, and *structural adaptability and design tensions* and to fulfill Objectives 1, 2, and 3 of this dissertation. In the following chapters, CYOA-CBL is tested in the field, analyzing data gathered during these evaluations to provide empirical evidence of its effectiveness.

[9] `https://miro.com/templates/buyer-persona/`
[10] `https://www.vuca-world.org`
[11] `https://www.opengroup.org/togaf`

While the framework was initially conceptualized as a work in progress, its theoretical contribution lies in several key areas.

First, by shifting the responsibility of structural choice to students, the framework aims to accommodate the wide range of attitudes and motivations found in computing curricula, particularly in mandatory courses.

CYOA-CBL has some limitations on the teaching side. The most critical, we believe, lies in the significant setup effort. In our previous experiences with CBL, teachers needed little preparation to run classes or mentoring sessions, relying instead on their extensive experience to adapt to the students' needs. With CYOA-CBL, teachers will need to devote significant effort in setting up the course's structure, preparing worksheets, and designing learning paths. However, CYOA-CBL is about improving CBL's long-term viability and scalability. The extensive experience of a teaching team cannot be taken for granted; indeed, many instructors who have historically taught this course will eventually step down. If a teaching team has limited access to experienced and flexible mentors, CYOA-CBL may offer a viable strategy to build teaching capacity by relying on a well-designed overarching scaffold. The paths-and-phases structure of CYOA-CBL, with its worksheets and exercise/reference libraries may aid teachers in focusing their improvisational and creative skills on students who wish to adopt open approaches, while providing high-quality exercises for those who prefer or need a structured approach.

Finally, and perhaps most innovatively, we see CYOA-CBL as an act of student empowerment. Traditionally, CBL adds complexity to the teaching context, and the design choices made by instructors may not align with students' needs. CYOA-CBL returns the decision of how much engagement and creativity students should invest in a course to the students themselves, giving them autonomy in their positioning in the structured-open spectrum.

In this chapter, we outlined our design for a possible pedagogical method that - despite requiring significant setup effort - overcomes several existing barriers to CBL adoption and allows students and teachers to adapt a course to their needs and resources. The hope is that these reflections can serve as a conversation starter within the computing and engineering education communities, promoting a broader discussion on CBL's alignment with student and teacher motivation and, ultimately, its pedagogical sustainability.

Chapter 6

Validating the CYOA-CBL framework: an iterative implementation in a mandatory curricular course

Following the theoretical definition of the "Choose Your Own Adventure in Challenge-Based Learning" (CYOA-CBL) framework in Chapter 5, this chapter shifts the focus from design to deployment and validation. It details a study spanning two academic years (2023/2024 and 2024/2025), where the framework was adopted, tested, and refined in a real educational setting.

As detailed in Chapter 5, CYOA-CBL aims to make CBL adaptable to different profiles of students, reduce the implementation load for teaching staff, and ultimately increase CBL's replicability and flexibility in different contexts. The goal of this chapter is to contribute to answering Research Questions 1 (RQ1) and 2 (RQ2) and to evaluate if and how CYOA-CBL can contribute to the Objectives 1 and 2 of this dissertation.

As anticipated in Chapter 3, to address this challenge, we employed a mixed-methods research design, specifically adopting a "concurrent triangulation design" [23]. We also embrace action research principles [5], iteratively testing and refining our methods and the CYOA-CBL framework based on findings from the first iteration. Accordingly, this chapter does not present a single snapshot, but rather an evolutionary process spanning two iterations of CYOA-CBL in a mandatory curricular course across two distinct student cohorts.

The content of this chapter integrates some findings from the following peer-review publication:

- **Enabling Computer Science Students to Choose Their Own Adventure**

in a Mandatory and Curricular Challenge-Based Learning Course
J. Lucchetta, S. Turrini, M. Stoycheva, M. Marchese, and L. Angeli
Published in 2024 IEEE Frontiers in Education Conference (FIE), Washington, DC, USA, 2024, pp. 1-8, doi: 10.1109/FIE61694.2024.10893335.

with new, unpublished data from the second iteration.

The overall results of the two iterations are currently being prepared for submission to an international journal on Computing Education[1]. With this work, we want to present some reflections on the implementation of this new approach based on data gathered from several sources. By sharing our experiences, insights, and points of improvement, we seek to contribute to the ongoing research on CBL in computing education, going towards making CBL more adopted in the CS learning environments.

To do so, we have define three secondary research questions that will guide the analysis of the data from the two iterations:

- SRQ1: Is it possible to design a CBL course that is not disorienting for students who need more guidance, but still flexible for those who want to freely explore open-ended challenges?
- SRQ2: How do the students perceive the value of the educational activities proposed with the CYOA-CBL in relation to the team's attitudes and preferences?
- SRQ3: Do the patterns of path selection and student engagement remain consistent across different cohorts, suggesting that CYOA-CBL is a reliable framework?

This chapter is organized as follows: Section 6.1 describes the pedagogical context of the course and details the participants involved in both cohorts. Section 6.2 outlines the research methodology, detailing the mixed-methods sequential explanatory design and the data collection. Section 6.3 presents the analysis of the first iteration, highlighting the initial validation of the concept and identifying the operational friction points. Section 6.4 serves as the connecting bridge, explaining the design decisions and refinements implemented in the framework based on the pilot feedback. Section 6.5 analyzes the results of the second iteration, focusing on the impact of the improved scaffolding tools on student experience. Finally, section 6.6 offers a general discussion, conducting a cross-analysis of the data to answer the research questions regarding the framework's adaptability, efficacy, and scalability.

[1]NOTE FOR REVIEWERS: ACM Transactions on Computing Education (TOCE) is the primary target.

6.1 Pedagogical context and implementation

To validate the feasibility of the CYOA-CBL framework as detailed in Chapter 5 and verify whether students understood the new course process and autonomously "choosing their own adventure" with the opportunity to customize their learning path, we deployed the CYOA-CBL within a real educational setting characterized by the typical constraints of computing and engineering education.

The study was conducted in fall 2023 and 2024 within the course "Innovation and Entrepreneurship Studies" (I&E Studies) at the University of Trento, a mid-sized European university. This is a 6-ECTS mandatory curricular course designed for second-year Master's students in computer science (CS) who are following a curriculum that integrates CS with Innovation and Entrepreneurship. The course runs for four months, from September to December, is delivered in English and represents the capstone module of a minor in I&E embedded within the technical curriculum.

Since 2017, the course has adopted a Challenge-Based Learning (CBL) methodology. Students are divided into teams and assigned to address a real-world open problem proposed by an external stakeholder (Challenge Provider). During the course, teams must identify and address the challenge within the context of their assigned case, such as considering alternative business models for a technological startup or analyzing go-to-market scenarios for the launch of a digital product. Students are required to ground their reflections by exploring specific areas like the business environment, competitors, suppliers, partners, environmental and sustainability issues, etc., using both deductive methods (i.e., through desk research) and inductive methods (i.e., through field work) as appropriate. This approach allows them to apply knowledge gained throughout their academic careers, particularly concepts related to I&E, to real-world problems.

Following the design principles detailed in Chapter 5, the course timeline was restructured to adopt the CYOA-CBL framework. The semester was divided into six distinct phases (as illustrated in Fig. 6.1), each corresponding to a stage of the CYOA-CBL process. In each phase, we organized two main activities: a tutorial and a mentoring session. The tutorial took place first and consisted of a regular two-hour class slot. During these sessions, teachers explained the main concept of the phase and proposed to the students small exercises to help them address the phase, that could be started in class, and continued at home. The week after each tutorial, teams attended mentoring sessions of 30 minutes, where the student team met with a pair of teachers. During mentorings, the team presented their work to the teachers, and students had

the opportunity to discuss any issues, receive feedback, and reflect on their progress. The mentoring sessions were guided by "mentoring worksheets", which served as both a checklist for students to ensure they had fulfilled all requirements for the phase, and as an assessment tool. Worksheets contained guiding questions such as *"Have you completed the suggested exercise for this phase?" or "Have you written a short meeting agenda with new content questions for the Challenge Provider?"* and were common to all groups.

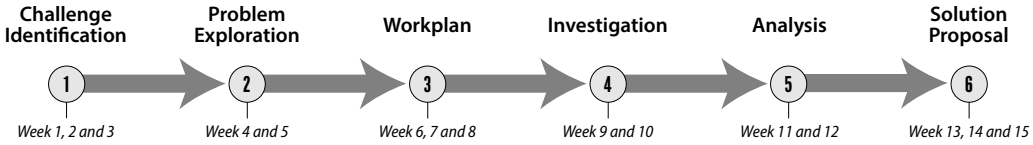


Figure 6.1: The division of the course in its six phases, marking what course weeks corresponded to each phase.

The course started, in phase 1, with a case presentation session, during which the Challenge Providers (CPs) described their challenges to the students, shortly followed by a class where students formed teams and bid on what challenges they wanted to work, while ensuring that each challenge had at least one team assigned to it. Usually, teams are of 4-5 members each and we have around 7 external entities (e.g., companies, public institutions, NGOs) that act as CP.

The course closed in late January, when each team prepared a 10-minute presentation of their solution proposal and submitted a final report detailing their work. For the report, we provided a template with suggested sections, but students were encouraged to modify the report's structure to align with the work they actually performed during the course.

6.2 Methodology

6.2.1 Research design overview

This study adopts an iterative mixed-methods action research design. Specifically, it follows the concurrent triangulation design principles [23], allowing for the simultaneous collection and subsequent integration of quantitative and qualitative data, with qualitative interviews embedded to enrich and contextualize the primary findings.

In alignment with action research principles [5], the study was executed across two distinct and sequential iterations. This strategy allows the research team to analyze data from the first cycle to implement improvements for the second.

The study was situated within the higher education context at the University of Trento, described in Section 6.1.

In all iterations, quantitative data were collected through structured surveys given to student teams at the end of each of the six CYOA-CBL phases, as well as through a final individual survey at the conclusion of the course.

To add context to these quantitative results and gain deeper insight into the learning process, qualitative data were continuously collected from five sources: open-ended survey questions for teams at the end of each CYOA-CBL phase; final open-ended survey questions for individuals at the end of the course; observational notes taken by researchers during class sessions; digital artifacts created by student teams using Miro; in-depth individual interviews conducted at the end of each course iteration with a voluntary group of students.

Rather than analyzing datasets in isolation, an iterative, interpretive analysis was employed to synthesize the findings. Descriptive statistics were used with the Likert-scale survey data to provide an initial overview of student satisfaction and understanding of the process. Thematic analysis [94] was used to both the open-ended survey responses, the observational notes and the interview transcripts. The thematic analysis initially adopted a deductive approach followed by an inductive coding approach [15], allowing existing theories to be investigated alongside critical themes regarding student narratives, challenges, and adaptation strategies that emerged directly from the data. This offers the depth needed to uncover the underlying reasons, mechanisms, and dynamics of students' experiences. The datasets of each iteration were integrated using a concurrent triangulation strategy. By cross-examining and merging the descriptive quantitative statistics with the qualitative themes, the study achieves a multi-faceted understanding of how the adaptive scaffolding impacted student learning. This integration serves to validate quantitative trends through narrative evidence and extending the scope of inquiry by capturing emergent themes from multiple perspectives and at different stages of the process that surveys alone could not measure. Additionally, the two iterations were used to improve the reliability and validity of this research and to discover other potential interesting points of discussion. Figure 6.2 presents an overview of the research design.

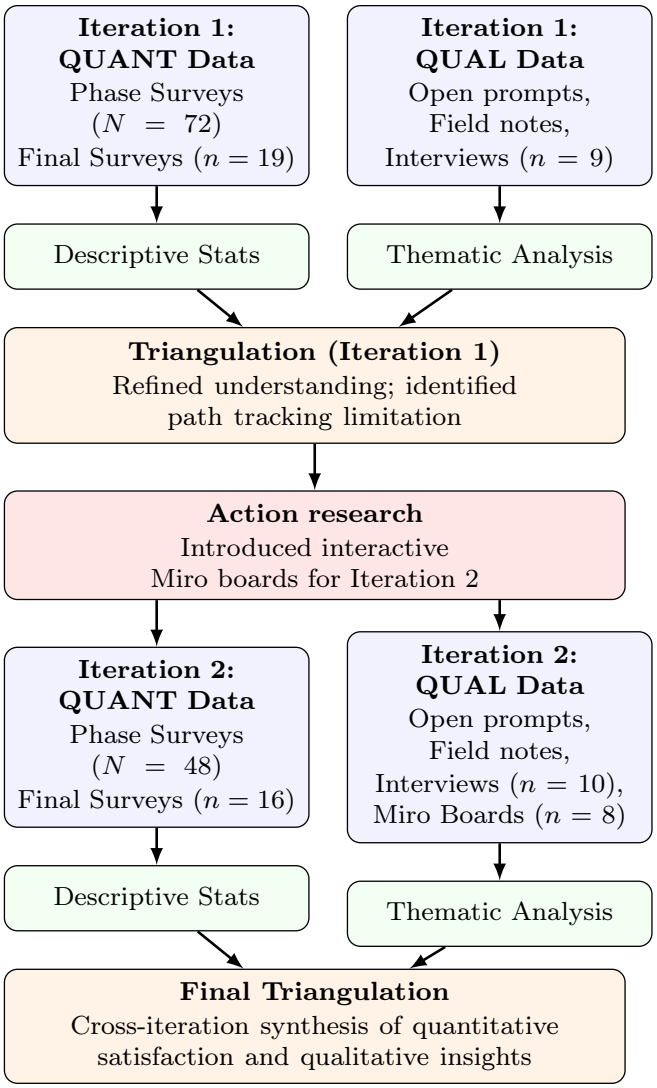


Figure 6.2: Methodological overview of the concurrent triangulation design within the action research cycle.

6.2.2 Participants and recruitment

The study involved Master's-level computer science (CS) students mandatory enrolled in the curricular course on Innovation and Entrepreneurship at the University of Trento described above. The total number of participants and team configurations varied across the two iterations of the CYOA-CBL framework (and the two editions of the course), as outlined in Table 6.1.

Context	**Academic Year**	**# Students**	**# Teams**	**Level**	**Participation type**
Curricular Course – Iteration 1	2023/2024	51	12	Master's (CS)	Mandatory course
Curricular Course – Iteration 2	2024/2025	33	8	Master's (CS)	Mandatory course

Table 6.1: Overview of study participants

While the course is structurally embedded within a technical CS curriculum, the student population is historically heterogeneous and highly multidisciplinary. The cohorts comprised students from double-degree programs that integrate technical competencies with business skills, including the EIT Digital Master School[2], EIT Urban Mobility[3], and EIT Manufacturing Master Schools[4]. Consequently, alongside students from pure ICT tracks and international exchange programs, the participants possessed diverse academic backgrounds in fields such as Human-Computer Interaction and Design, Statistics, Mechanical Engineering, and Business. This unique cultural and disciplinary diversity makes the cohort an ideal testbed for evaluating an adaptive framework like CYOA-CBL, as students brought varied preferences and collaborative expectations to the project workflows.

While course enrollment was mandatory as part of the degree requirement, participation in the research study (filling out surveys and engaging in interviews) was voluntary. All students who completed the course were included in the study. Since the CYOA-CBL framework was adopted during the mandatory course, participation in the pedagogical activities was required as part of the course requirements. However, a clear distinction was maintained between the educational intervention and the research study. While the pedagogical model was compulsory, participation in the research with surveys

[2] `https://masterschool.eitdigital.eu`
[3] `https://www.eiturbanmobility.eu`
[4] `https://www.eitmanufacturing.eu`

and semi-structured interviews was voluntary. Participants were recruited through course enrollment and comprehensive information regarding the study's objectives, data handling protocols, and consent procedures was provided to all participants prior to any data collection.

Due to structural and temporal constraints, it was unfeasible to conduct in-depth interviews with all the students of the course. Therefore, to ensure a balanced and informative representation of student experiences, a purposive maximum variation sampling strategy was employed for the interviews. Participants for the individual interviews were primarily selected based on two key indicators: their final course grade (as a proxy for academic performance) and field notes recorded by the teaching staff regarding real-time team dynamics, level of engagement, and collaborative friction. These two dimensions served as the main criteria for sampling, aimed at capturing a spectrum of experiences with the CYOA-CBL framework. Additional variables, such as gender, academic track, country of origin (Italy, EU, or non-EU), learning modality (online or in-person), and assigned mentor (M1 or M2), were considered as control variables to ensure heterogeneity and contextual depth across the sample. This approach supported an in-depth understanding of how different learner profiles interacted with and perceived the CYOA-CBL structure. Table 6.2 provides a detailed breakdown of the interview participants' profiles based on the selection criteria and the corresponding academic year, offering a transparent overview of the diversity across the two iterations of the study.

6.2.3 Data collection

This study adopted an iterative mixed-methods action research design, which can be conceptualized as a concurrent triangulation design [23] across two consecutive editions of the mandatory curricular course described in Section 6.1. To gain a comprehensive understanding of the pedagogical framework and answer the research questions, we collected both closed-ended information (e.g., Likert-scale survey answers) to capture broad patterns in student satisfaction and process understanding, and open-ended information (e.g., semi-structured interviews, artifact observations, and open survey responses) to uncover the underlying dynamics and qualitative nuance of the students' experience.

The design consists of distinct phases, inspired by the approach used by Doulougeri et al. in a study on factors influencing students' experience with CBL [30]:

1. an anonymous group-based phase survey delivered at the end of each phase of

Criteria	**Variable**	**AY 2023/24**	**AY 2024/25**
Gender	Male	5	4
	Female	4	6
Course track	Autonomous Systems	0	1
	Data Science	3	4
	HCID	1	2
	Fintech	1	0
	Business	1	0
	Cybersecurity	2	3
	Information Engineering	1	0
Origin country	Anonymous	4	3
	Other EU Students	4	3
	Non-EU Students	1	4
Grade	$> 25/30$	7	9
	$\leq 25/30$	2	1
Experience	In Presence	8	10
	Online	1	0
Mentor	Mentor 1	6	5
	Mentor 2	3	6

Table 6.2: Overview of interview participants by demographic and academic year.

the course, providing a general understanding of students' comprehension of the process (named "phase survey") with both open and close-ended questions [30];

2. an anonymous individual survey at the end of the course to gather general impressions on the course and validate the results that we had from the phase surveys (named "final survey") with both open and close-ended questions;

3. in-depth semi-structured interviews to further refine and explain the results by delving into students' views in more depth [23, 30];

4. observations from the teaching staff regarding the student teams dynamics.

Additionally, for the second iteration and in line with the action research principle we improved the data collection strategy and we replaced the static path-tracking surveys used during the first iteration. Instead, we asked each team to use a Miro board [5] - a

[5] `https://miro.com/`

digital collaborative whiteboard platform - to get more precise evaluation of the path taken by each group of student.

The data collection procedures are described below, presented separately for the quantitative and qualitative phases in chronological order.

Quantitative data collection

The quantitative data were collected through structured surveys provided via Google Forms. As described before, two types of surveys were employed: one distributed after each of the six phases of the CYOA-CBL process ("phase survey"), and one final survey conducted at the end of each course iteration ("final survey").

The logic of the phase surveys follows the approach of Chanin et al., who asked students to complete a survey at the end of each phase of their process to evaluate a framework for a CBL course [19]. The primary objective was to gather reflections on what students learned or struggled with, assess the effectiveness of tutorials and mentoring sessions, and determine which path students followed. The phase surveys were filled out collaboratively by each student team at the conclusion of every CYOA-CBL phase and it included closed-ended questions using a 5-point Likert scale.

The final survey was a standard, individual evaluation survey administered to all students at the end of the course to assess overall satisfaction and specific course components. It served to gather more comprehensive personal reflections on the overall learning experience. The survey consisted of closed questions on a 5-point Likert scale, similar to the previous one, ranging from "strongly disagree" to "strongly agree".

All surveys were completed anonymously to minimize potential bias and ensure that students could provide honest feedback without concern for academic consequences. Surveys were administered before final grades were released, and students were not identifiable by instructors.

Qualitative data collection

The qualitative phase consisted of teacher's observations, few open-ended prompts in the phase and final surveys, artifacts from the Miro board (only in the second iteration) and semi-structured interviews with a voluntary subset of students.

The short open-ended questions of the two surveys were designed based on a similar study presented by Detoni et al. [29] and adjusted to fit the context of this research. The open-ended questions in the phase survey used the following prompts:

- *In one word, what did you learn the most during this phase?*

- *In one word, what did you struggle the most with during this phase?*
- *In one word, what would you have done differently in the tutorial/mentoring for this phase?*

The open-ended questions in the final survey used the following prompts:

- *Please explain if and why how we conducted the course satisfied you*
- *Please explain what was the most problematic aspect of the course for you*
- *Please explain if you would propose this methodology again in the next year, and indicate strengths and weaknesses*

The semi-structured interviews, were crucial for the research design, helping to refine and explain the data gathered during the course. Student interviews were conducted only after the end of the course, once grades had already been assigned and finalized. This timing was intended to reduce potential bias and ensure students felt free to speak openly. Students did not receive any course credit or any incentive for consenting to data collection, and they did not have any penalty for declining to participate in the study.

Participants were encouraged to discuss their experiences with the course and the CYOA-CBL methodology overall. We asked about their challenges throughout the course, how they worked and structured their process and their thoughts on the various activities within the course. Each interview lasted approximately 30-45 minutes. Most of them were conducted online via video conferencing. Interviews were held in English, except when the participant was a native Italian speaker; in such cases, the conversation was held in Italian to ensure the students felt comfortable with their native language when possible. Interviews conducted in Italian were carefully translated by us without altering meanings or phrases.

Data collection totals

Across both course iterations, data collection yielded a total of 120 team-level phase survey responses, 35 individual final course evaluation survey responses, and 19 semi-structured participant interviews.

More specifically, a total of 120 team-level responses were collected across the two iterations of the curricular course. In Iteration 1, 12 teams completed surveys across 6 phases ($12 \times 6 = 72$ responses). In Iteration 2, 8 teams completed surveys across 6 phases ($8 \times 6 = 48$ responses).

The individual final evaluation survey yielded an overall response rate of 41.7% (35/84 students). In Iteration 1, 19 out of 51 enrolled students responded (37.3%), while in Iteration 2, 16 out of 33 enrolled students responded (48.5%).

A total of 19 individual interviews were conducted following the conclusion of the courses: 9 following Iteration 1 and 10 following Iteration 2. Interview durations ranged from 30 to 45 minutes.

Table 6.3 provides a comprehensive implementation matrix mapping the research aims, data sources, formats, collection timing, and participant sample sizes across both iterations.

Data source	**Data format**	**Level & timing**	**Primary research aim**	**Sample size / extent**
Phase surveys	Closed-ended (Likert) and short open-ended prompts	Team-level; administered at end of each of 6 phases	Evaluate phase-specific process understanding, mentoring efficacy, immediate struggles and path choices	Iteration 1: 12 teams × 6 phases = 72 responses Iteration 2: 8 teams × 6 phases = 48 responses *Total: 120 team responses*
Final survey	Closed-ended (Likert) and open-ended prompts	Individual-level; end of course	Assess overall course satisfaction, overall learning gains, and structural feedback	Iteration 1: 19 / 51 students (37.3%) Iteration 2: 16 / 33 students (48.5%) *Total: 35 individual responses*
Semi-structured interviews	Audio-recorded open-ended transcripts	Individual-level; post-grading period	Explain quantitative trends; explore deep student experiences, challenges, and path choices	Iteration 1: 9 participants Iteration 2: 10 participants *Total: 19 interviews (30–45 min, M = 37.2 min)*
Miro boards	Visual artifacts	Team-level; during the course period (Iteration 2)	Map real-time team path trajectory	Iteration 2: 8 visual team boards
Teachers notes	Qualitative field notes	Teacher-level; ongoing throughout course	Document classroom and teams dynamics	Ongoing observation across both iterations

Table 6.3: Implementation matrix of data collection sources across Iterations 1 and 2.

6.2.4 Data analysis

Quantitative and qualitative data were collected concurrently during the course offerings and analyzed independently using method-appropriate techniques. The results were then integrated during the interpretation phase to cross-validate, corroborate, and triangulate findings across data sources.

Quantitative data analysis

Quantitative analysis was conducted to establish statistical patterns regarding student satisfaction, process understanding, team path choices, and perceived scaffolding utility across both course iterations.

Primary data collected from the phase surveys and the final surveys were aggregated and analyzed using descriptive statistical techniques. For the phase-by-phase Likert-scale items evaluating tutorial effectiveness, mentoring effectiveness, and next-step clarity, arithmetic means (M), standard deviations (SD), and modal scores were computed. Then, data regarding teams' path choices (only for iteration 1) were analyzed using stacked bar charts. This visual representation enabled us to track the absolute frequency and distribution of student teams selecting specific paths (e.g., *Business modelling*, *Market analysis*) across the sequential phases of the course (from phases 2 to 6). Finally, for the final survey, ordinal response data were summarized using percentages, modal choices, means and standard deviations to measure student engagement, structural clarity, and activity utility.

Qualitative data analysis

For qualitative data, comprising open-ended survey entries, transcriptions of semi-structured interviews, instructor observation field notes, and visual artifacts from Miro boards, we performed a Thematic Analysis adhering to the six-phase thematic framework of Braun and Clarke [15]. Audio recordings of the interviews were transcribed using Whisper executed locally to safeguard participant privacy and minimize data exfiltration risks. Subsequent qualitative coding was facilitated using NVivo Software (version 14).

As mentioned previously, we adopted a combined deductive and inductive coding strategy [15]. While initial coding was guided by theoretical concepts identified in the literature, we avoided forcing the data into a rigid predefined structure. Instead, additional codes and overarching themes were allowed to emerge organically from the data. This hybrid approach allowed us to leverage domain expertise while ensuring

that the analytical categories captured participants' experiences, unexpected decision patterns, and self-reported challenges.

Mixed methods analysis and data triangulation

In accordance with the concurrent triangulation design, the quantitative and qualitative findings were integrated during the final synthesis phase to compare, contrast, and corroborate results.

Quantitative statistical trends were placed side-by-side with qualitative themes, direct quotes, and Miro board visual path tracking corresponding to the same phase. This comparison served to determine where qualitative student narratives converged with, expanded upon, or contradicted quantitative feedback, producing a multi-source evaluation of the CYOA-CBL methodology.

6.2.5 Methodological integrity

To establish the credibility and transferability of our findings, this study established criteria for methodological integrity in computing education and mixed-methods research [23, 15]. We implemented explicit strategies across four core dimensions of rigor: credibility, transparency, reflexivity, and transferability.

Data were collected across two distinct offerings of the course, encompassing 20 distinct student teams ($N = 84$ total enrolled students). This sample structure captured a rich diversity of team dynamics, academic backgrounds, and non-linear pathway choices across the CYOA-CBL framework.

Credibility was supported through data source triangulation and supplemental analytic checks. In accordance with our concurrent triangulation design, claims were cross-validated across four distinct qualitative and quantitative data streams: individual Likert survey items, open-ended survey prompts, interview transcripts, and interactive Miro board visual tracking artifacts. Results were only synthesized when corroborated across multiple sources. When discrepancies emerged between quantitative feedback and qualitative narratives, these divergent instances were explicitly analyzed rather than dismissed. To ensure findings remain transparently grounded in evidence, qualitative claims in Sections 6.3 and 6.5 are accompanied by direct participant quotes, explicitly contextualized with the course iteration.

The research team involved in this study comprises this author and members of the *CRIT Research Group*[6], who collectively conceptualized and designed the CYOA-CBL

[6] `https://critlab.eu/en/Staff`

methodology (see Chapter 5). The group's expertise in CBL is grounded in years of practical implementation, having adopted CBL as the core pedagogical approach in multiple higher education course editions since 2017. This background provides the research team with a deep understanding of the strengths and limitations of CBL, as well as the common challenges students face during its implementation. Because the primary researchers served the dual roles of course designers/instructors and data analysts, structured practices were embedded to mitigate researcher confirmation bias, power asymmetries, and social desirability effects. The intention was mainly focused to explore how students engaged with the framework, how they interpreted its flexibility, and how it impacted their learning and autonomy within this CBL approach rather than evaluating teacher performance. Qualitative analysis was conducted also inductively, allowing themes to emerge directly from participant accounts rather than forcing data only into pre-existing theoretical constructs or instructor expectations. However, we explicitly acknowledge that the analysis of the second course iteration was reflexively informed by the initial thematic analysis developed during the first iteration. Rather than treating the two cohorts as entirely isolated, the findings from the first iteration acted as a first lens during the analysis of the second cohort. To manage this analytical bias and remain open to novel phenomena, researchers actively looked for disconfirming evidence, contrasting dynamics, and newly emerging themes specific to the second iteration.

Student interviews were conducted only after the official conclusion of the course and the public posting of final grades. This timing explicitly separated participation from academic assessment, ensuring students could critique the CYOA-CBL model without fear of grade penalties.

All phase and final evaluation surveys were submitted anonymously via forms, preventing instructors from associating feedback with individual student identities during the active semester. Instructors maintained ongoing observational field notes during weekly mentoring sessions. These notes were used during thematic analysis to bracket personal assumptions and distinguish direct student observations from instructor interpretations.

To ensure transparency and to enable readers and educational practitioners to assess the transferability of our findings to other computer science courses, we provide "thick descriptions" of the research setting. Section 6.1 explicitly details the pedagogical background and course structures, while Section 6.2.2 presents the demographic breakdown and 6.2.3 the implementation matrix.

6.2.6 Limitations

This study is subject to several limitations regarding its context, sample size, and methodology.

The results are bound to the specific educational context in which the study was developed. Influencing factors include the specific type of course, the students' curricula, and the local university environment. Consequently, the generalizability of the findings is limited; the results may not be directly applicable to different academic cultures or educational settings that were not evaluated in this study. For instance, the dynamics observed within this specific class cohort may not reflect those of broader student populations.

Furthermore, while the cumulative data spans two years, the sample size for the final survey (35 responses) and interviews (19 participants) is limited. This means that the answers may only partially represent the students' opinions and understanding.

Finally, the use of judgment sampling introduces potential biases. As samples are selected based on the expert's assessment of suitable participants, this method restricts the types of statistical analyses that can be performed [25]. However, statistical inference was not the primary goal of the interviews, which were instead designed to deepen the understanding of survey responses.

Crucially, the study is subject to the risk of confirmation bias and interviewer bias. Regarding the qualitative interviews, although a set of questions was employed to guide the interviews and allow consistency across all participants (see Appendix G), the interaction itself presents a limitation. There is a risk that the interviewer may have inadvertently guided the answers or interpreted the responses in a way that aligns with pre-existing hypotheses, rather than capturing the students' uninfluenced perspectives.

The findings presented in the next section are the outcome of the analysis described in the methodology.

6.3 Findings from iteration 1 (AY 2023/2024)

Quantitative findings

As described in Section 6.2.3, feedback was collected at the end of each process phase (phases 1 through 6) to evaluate student group perceptions across three core dimensions (see Table 6.4) using a 5-point Likert scale: tutorial effectiveness, mentoring effectiveness, and clarity of next steps. An analysis of the 72 responses from the first iteration shows that, overall, the mentoring sessions maintained high ratings throughout

the intervention (M = 4.2 SD=0.2), reaching a peak average of M=4.4 (SD=0.7) during Phase 5. In contrast, tutorial effectiveness yielded an overall mean of 3.9 (SD=0.3), exhibiting greater initial variance and lower satisfaction in Phase 1 (M=3.5 SD=1) before stabilizing and peaking in Phase 2 and 5 (M=4.2 SD=0.4). The clarity of next steps averaged 4.2 (SD=0.3) across all phases, following a steady trajectory across the course progress.

The "clarity of the next steps" evaluations provide useful insights into student navigation within CBL environments. CBL literature suggests that the primary critical friction points occur during the initial stages, where students face substantial ambiguity regarding open-ended challenges [33]. In contrast, our phase data indicates high early clarity that experienced a minor dip during intermediate execution (Phases 2 and 4) before rising (M=4.4 SD=0.7) in the final stages. Throughout this trajectory, mentoring consistently received higher evaluations than tutorials, emphasizing the value of personalized, adaptive guidance during execution phases.

Phase	**Tutorial effectiveness**	**Mentoring effectiveness**	**Clarity of next steps**
Phase 1	3.5 ± 1	4.2 ± 0.7	4 ± 1.1
Phase 2	4.1 ± 0.4	3.9 ± 0.6	3.9 ± 0.8
Phase 3	3.7 ± 0.5	4.2 ± 0.9	4.2 ± 0.6
Phase 4	3.7 ± 0.7	3.9 ± 0.8	3.9 ± 0.7
Phase 5	4.2 ± 0.4	4.4 ± 0.7	4.5 ± 0.7
Phase 6	4 ± 0.7	4.3 ± 0.7	4.4 ± 0.7
Overall mean	**3.9 ± 0.3**	**4.2 ± 0.2**	**4.2 ± 0.3**

Table 6.4: Descriptive statistics across process phases (Mean ± SD) of 12 teams × 6 phases = 72 responses.

In each phase's survey, we asked students what path they were following and we summarised in Figure 6.3 the number of teams that chose a specific path during the various phases. By combining the responses of the teams for each phase, we have seen how some groups followed a clear linear process where they stuck with the same path (which we take as a proxy of the students following a structured approach), while others changed direction and paths more frequently (which we take as students opting for an open approach).

Three out of twelve teams adopted a structured approach, while the others opted for an open or in-between approach. For instance, Team 5 started its work with a business-oriented path but later changed direction to a technological analysis, whereas Team 11 started with a market analysis/scenario collection and concluded the project

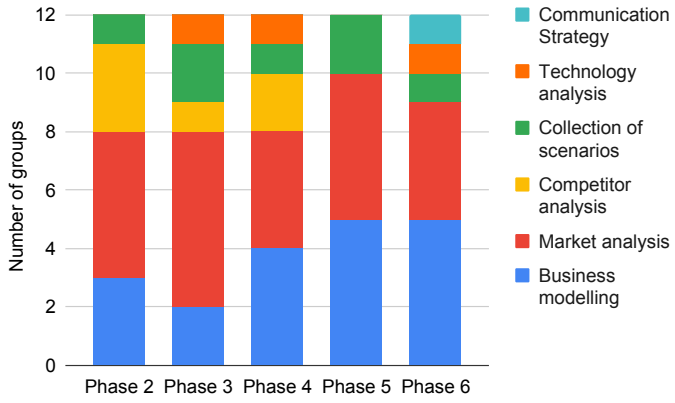


Figure 6.3: Stacked bar chart showing the number of groups per path.

with a communication strategy. All in all, three teams never changed paths; six teams changed paths once; two teams changed paths twice, and one team changed paths three times. Notably, even the teams that changed paths multiple times never did so in two consecutive phases.

Table 6.5 and Table 6.6 reports the statistical distribution of student evaluations across some course dimensions and perceived activity effectiveness gathered through the "final survey". It provides a broader evaluation of the overall student experience on a 5-point scale. Responses were collected from N=19 out of 51 enrolled students. Given the small sample size (N=19), each participant accounts for 5.26% ((1/19) * 100, i.e., +/- 0.05) of the total. Over 63% of respondents categorized mentoring sessions and meetings with the challenge provider as extremely helpful. High levels of satisfaction were also reported for the clarity of mentoring worksheets (68.4% "excellent") and direct engagement with teaching staff (73.7% "excellent"). Conversely, student ratings for tutorials were more widely distributed, with 26.4% of respondents indicating that tutorials were either "not at all helpful" or only "slightly helpful". This distribution aligns with the phase-level findings and highlights tutorial structure as a key area for enhancement in future course deployments.

Qualitative findings

Qualitative findings for the first iteration were established through a thematic analysis triangulating semi-structured participant interviews (N=9), teacher observational notes, open-ended responses from the "phase surveys" (Phases 1–6), and the "final survey". This synthesis revealed three central themes regarding student experiences during the initial deployment: (1) team navigation of open versus structured paths, (2) the

Dimension	**Poor**	**Fair**	**Okay**	**Good**	**Excellent**	**Mode**
Level of engagement in course	1 (5.3%)	0 (0%)	6 (31.6%)	8 (42.1%)	4 (21.1%)	Good
Clarity of next steps	0 (0%)	1 (5.3%)	2 (10.5%)	3 (15.8%)	13 (68.4%)	Excellent
Clarity of general process	0 (0%)	2 (10.5%)	4 (21.1%)	4 (21.1%)	9 (47.4%)	Excellent
Engagement with teachers	0 (0%)	0 (0%)	3 (15.8%)	2 (10.5%)	14 (73.7%)	Excellent
Engagement with Challenge Provider	1 (5.3%)	0 (0%)	2 (10.5%)	4 (21.1%)	12 (63.2%)	Excellent
Teamwork with fellow students	0 (0%)	0 (0%)	3 (15.8%)	4 (21.1%)	12 (63.2%)	Excellent
Clarity of mentoring worksheets	0 (0%)	0 (0%)	0 (0%)	6 (31.6%)	13 (68.4%)	Excellent

Table 6.5: Statistical distribution of the students' evaluation of course dimensions (N = 19 out of 51).

Activity	**Not at all**	**Slightly**	**Somewhat**	**Very**	**Extremely**	**Mode**
Tutorials	1 (5.3%)	4 (21.1%)	5 (26.3%)	4 (21.1%)	5 (26.3%)	Somewhat
Mentoring sessions	0 (0%)	1 (5.3%)	2 (10.5%)	4 (21.1%)	12 (63.2%)	Extremely helpful
Meetings with CP	0 (0%)	0 (0%)	2 (10.5%)	5 (26.3%)	12 (63.2%)	Extremely helpful

Table 6.6: Statistical distribution of perceived activity effectiveness (N = 19 out of 51).

scaffolding, autonomy, and pacing afforded by the CYOA-CBL framework, and (3) a sharp divergence in the perceived utility of mentoring versus tutorials.

Structured or open approaches.

A central finding across participant accounts was the explicit recognition of team agency in selecting, maintaining, and adapting project pathways. Rather than enforcing a rigid methodology, the CYOA-CBL framework granted teams the freedom to align their process with their emerging project goals. While some groups maintained a consistent path, others adapted their approach as new information surfaced. For instance, Student 3 noted that their team "stuck to the same [path], but we had some variation towards the end when we found more relevant data". Similarly, Student 7 highlighted the contrast between traditional course expectations and the agency granted by the framework:

> "We stuck [to the same path] from the beginning [but] I was surprised by the fact that we didn't really have to do a business model during the course. [The course] was more open [...] we weren't expecting to have [the possibility of doing a marketing strategy]."

This sense of ownership was reinforced by Student 3, who emphasized that course execution was governed "more like what the expectations that we had as a team more than what the professor or the course had upon us". Furthermore, Student 1 explained how they changed path more than once during the process. In the beginning, the team narrowed down two options, and chose one of the two. However, after collecting some field data, the team understood it was not the right decision, and shifted to the other option and followed it until the end:

> "Let's say, perhaps our mistake was assuming that was the right way to go.".

Teacher observations and final deliverable reviews confirmed that teams on identical pathways personalized their analytical tools and final artifacts to suit their specific challenge needs. For example, when conducting market analysis, one team combined expert interviews with user surveys, while another relied primarily on desk research analyzing industry size and market dynamics. Students actively adapted deliverable structures rather than treating templates as rigid constraints. As Student 8 reflected:

> "Even in the final report, we indeed added sections and removed some that did not fit our work. So we always adapted, trying to follow the instructions well or poorly, but we adapted to our case.".

Scaffolding, autonomy, and pacing.

The integration of real-world challenges fostered high student involvement and project ownership. Students reported that addressing real-world problems created a sense of "extra responsibility". Students noted that the predefined process structure of CYOA-CBL made open-ended challenges approachable, transforming what could have been a disorienting experience into a manageable, step-by-step workflow.

Open-ended challenges require higher creative effort [11] and it was appreciated by Student 4, who enjoyed "brainstorming and being a bit more creative instead of just studying from books". However, some students recognized that structural guardrails of CYOA-CBL prevented disorientation. Student 9 noted that "having the structure like that certainly helped a bit because you had the stakes marked, so you weren't too free to get lost who knows where". Student 8 summarized this balance as an optimal middle ground:

> "If we had been freer, there would have been the real risk of taking a direction very far from what you actually want, and the risk of digressing. But if it had been more detailed, they would have left us little space to do what we wanted. [The proposed structure] was a good compromise.".

One student wrote: "The main strength is the flexibility and dynamic nature of the course structure.". Someone else added: "The course was conducted in a structured way since the beginning; [however] it really felt like we own the course and there was a sense of extra responsibility.".

This scaffolding directly influenced project pacing and workload management. Bi-weekly mentoring sessions and structured phase worksheets established a continuous work rhythm that prevented end-of-semester delivery stress. Student 5 explained that bi-weekly progress updates forced the team to work "each and every week," contrasting this with traditional courses where work is back-loaded into the final weeks. Student 5 added: "I didn't feel that much pressure [...] because when you are working every week, and you have a work progress in line, then you don't feel too much pressure all of a sudden." Student 1 similarly noted that involved company mentors and self-paced progress allowed them to "delve into the challenge at our own pace throughout the whole process.".

However, one interview revealed a complementary challenge regarding long-term semester pacing. Despite the mentoring sessions, students noted difficulty sustaining internal motivation across a four-month project without formal intermediate checkpoints:

> "I think [...] the semester is quite long. I'm not used to, to work on a project for [so long time]. So [...] maybe like a midterm presentation, which is part of your grades [can] motivate [the group] to work on it in like halfway.".

Analyzing open-ended questions revealed how student struggles evolved across project stages. Early phases (Phases 1–3) involved cognitive alignment hurdles, such as defining project scope and establishing team roles. Intermediate phases (Phases 4–5) presented severe operational bottlenecks in field research, including difficulties formulating survey instruments, recruiting participants, and obtaining specific market data. In Phase 6, challenges shifted toward synthesizing broad findings into a concise, prioritized solution. Adding to these internal hurdles, several groups faced friction from unresponsive Challenge Providers. While frustrating, this external ambiguity ultimately forced teams to exercise self-direction, construct contingency plans, and take full ownership of their project outcomes.

Divergent utility of mentoring versus tutorials.

A prominent theme across all qualitative data streams was the contrast in how students evaluated instructional support activities. Bi-weekly mentoring sessions were praised as the most valuable component of the course. Students emphasized that individual group mentorship provided essential progress checks, validated strategic decisions, and offered clear actionable steps.

Conversely, perceptions of tutorials were deeply divided. For less structured or struggling teams, tutorial exercises provided a helpful collaborative space to advance project tasks. Student 6 appreciated in-class group activities and student 5 noted that "we had really good conversations during the tutorials... it's the best part of the course where we can share ideas". However, for highly self-directed teams, tutorials were frequently perceived as redundant or misaligned with their pace. Student 8 criticized in-class exercises:

> "I didn't fully understand the point of working in class [during tutorials] because then we always did it again at home in a more thorough way. For our group, doing the in-class part wasn't particularly useful... For me, they should be more frontal lessons.".

Student 9 similarly observed that because their group was ahead of schedule, tutorials felt repetitive. Interview data indicated that while a minority of students preferred retaining tutorials as structured co-working sessions, the majority recommended restructuring them to include more frontal theoretical lectures, advanced

domain content, or challenge-tailored examples. As Student 4 observed, a key structural challenge was that "every group has their own challenge, their own work, and their own timeline", making generic tutorial content inherently difficult to calibrate across heterogeneous project teams.

6.4 Refining the framework: from iteration 1 to iteration 2

The initial deployment of the CYOA-CBL framework (Iteration 1, AY 2023/2024) provided a proof of concept that the tension between structured CBL courses and student autonomy can be mitigated by allowing teams to self-regulate their level of structure. However, following the action research principles, the analysis of the first iteration highlighted specific friction points that required intervention [5].

While students validated the core philosophy of the framework, qualitative feedback exposed areas where the CYOA-CBL needed fine-tuning. Specifically, the tutorials were appreciated only partially, and the long duration of the project led to motivation drops in the middle of the semester. Furthermore, the mechanisms for tracking the chosen "adventure" with surveys were not sufficient for capturing the nuance of student workflows.

Based on these findings, we developed CYOA-CBL Iteration 2 for the AY 2024/2025, introducing three practical improvements: more additional materials for the tutorials, a mid-term presentation, and a visual tool to track the learning path.

6.4.1 Modular support

In the first iteration, tutorials received mixed feedback: highly autonomous teams often found tutorials redundant or too slow, while teams requiring more guidance felt they were essential and sometimes insufficient.

To address this polarity, in the second iteration, we restructured the educational content to be more flexible. We acted in two ways, with extra content and with the introduction of external experts.

We kept the tutorials to ensure a baseline of theoretical knowledge and to propose exercises guiding teams through each phase. However, we shifted the focus towards "active work in class", allowing autonomous teams to speed through the theory and use the slot for team-building or advancing their project.

Then, to increase engagement and provide a broader perspective, we integrated an extra appointment featuring a keynote speaker who held a 2-hour lecture on innovation and entrepreneurship themes. This was done to answer the students' request for more "real-world" context outside of the standard academic theory.

Finally, for groups facing specific content-wise hurdles (e.g., specific business modeling), we moved from teaching everyone everything to providing specific material only to the groups that requested or needed it.

6.4.2 Midterm presentation

A critical insight from the first iteration came from the semi-structured interviews. One student explicitly highlighted the difficulty of maintaining motivation over a four-month semester without intermediate checkpoints.

To address this feedback and help students manage the long timeframe of the course, we introduced a mid-term presentation in the second iteration. During this session, teams had 5 minutes to present their progress to a panel composed of their mentors, mentors from other groups, and external professors.

The presentation was scheduled between Phase 3 and Phase 4 of the CYOA-CBL framework. This moment marks the midpoint of the process, right after the "Workplan" phase. This timing allows teams to receive support on their proposed strategy, using the feedback to improve their plan or adjust their research direction before moving forward.

Building on the feedback from the first iteration, this intermediate presentation is designed to sustain student engagement throughout the middle of the semester. It helps distribute the workload, preventing accumulation at the end of the course, and mitigates the potential decline in motivation that often follows the initial phase. Furthermore, it offers a structured opportunity for feedback, enabling groups to validate and refine their work prior to the final deadline.

6.4.3 Visualizing the "adventure"

Another significant addition in the second iteration was the integration of Miro, a digital collaborative whiteboard platform, to replace the static path-tracking surveys used during the first iteration.

In the first iteration, we asked teams to "categorize" their path (e.g., *"we are doing a tech path"*). However, after the analysis of the results, we thought it was too abstract and we wanted to have a deep understanding of the teams "adventure". For this reason,

for the second iteration, we designed for each team a custom "CYOA-CBL Board" on Miro (see Figure 6.4). This digital workspace allows students to visually map their journey in real-time, making the abstract concept of "choosing a path" more tangible.

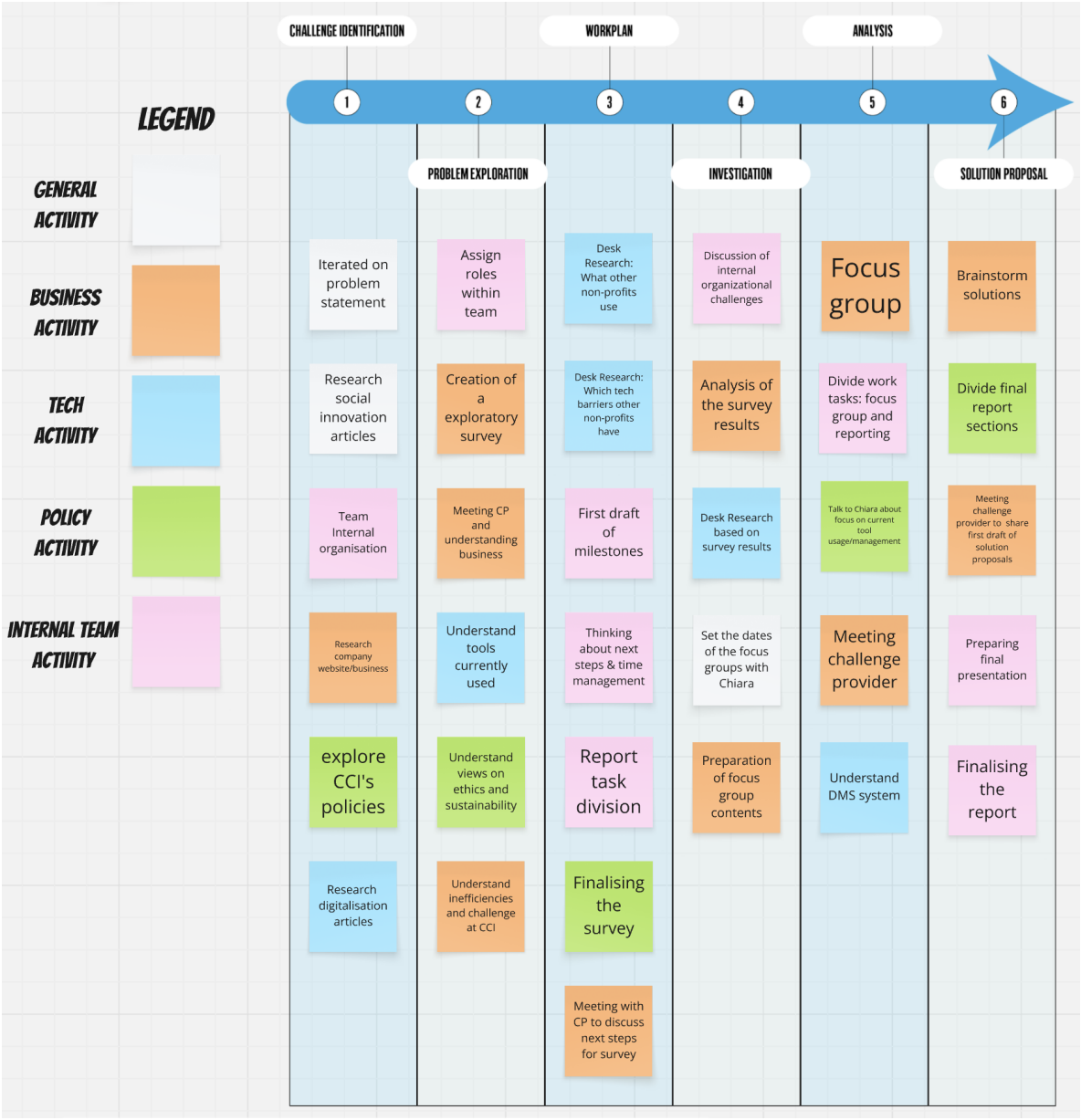


Figure 6.4: The "CYOA-CBL Board" on Miro used in Iteration 2 by Team 1. The horizontal axis represents the course timeline (Phases 1-6), while the vertical arrangement and color coding represent the type of activity performed by the team.

As shown in Figure 6.4, the board functions as a dynamic timeline divided into the six phases of the framework (from Challenge Identification to Solution Proposal). Instead of selecting a pre-defined label, teams were asked to populate the board with

specific activities they performed during each phase. To enable immediate visual analysis of the "type of adventure" the team is living, we introduced a color-coded legend:

- **General activity (white):** like standard course requirements;
- **Business activity (orange):** for example, market analysis, competitor research, business modeling;
- **Tech activity (blue):** for example, technical feasibility, prototyping, software architecture;
- **Policy activity (green):** for example, legal analysis, sustainability, ethics, GDPR compliance;
- **Additional activity (custom color):** teams could decide if their activities were of another type. In this example, this team chose the color pink to describe the internal team activities.

The figure depicts a real example of a team's journey. It is immediately visible how this specific team balanced their effort: they began with a strong focus on internal team activities (Pink) and general activities (White) during the "Problem Exploration" phase (Phase 2), likely to solidify their group dynamics. As they progressed to "Investigation" (Phase 4) and "Analysis" (Phase 5), the board shows a shift towards business activities (Orange), with "Focus Group" and "Analysis of survey results", while maintaining a consistent thread of technical research (Blue) throughout the middle phases.

This visualization serves a dual purpose: it provides researchers and mentors with a granular view of the team's actual workflow, and it acts as a visual tool for students, helping them realize where they are investing their energy and identify potential gaps in specific dimensions of the challenge.

6.5 Findings from iteration 2 (AY 2024/2025)

6.5.1 Quantitative findings

Even for the second iteration, quantitative findings were derived from both the "phase surveys" administered across the six course phases and the "final survey".

Across the six phases (see Table 6.7), student groups evaluated clarity of next steps highest overall (M=4.1 SD=0.5), closely followed by mentoring effectiveness (M=4

SD=0.2), while tutorial effectiveness received lower and more variable ratings (M=3.7 SD=0.4). The data highlights that while procedural clarity steadily climbs from initial ambiguity to final project delivery, mentorship acts as a crucial continuous anchor, particularly during initial problem framing and midpoint execution.

Phase	**Tutorial effectiveness**	**Mentoring effectiveness**	**Clarity of next steps**
Phase 1	3 ± 1.1	4.2 ± 0.7	3.3 ± 1.4
Phase 2	4 ± 0.9	4 ± 0.8	4.1 ± 1.1
Phase 3	3.9 ± 0.8	4 ± 0.8	3.9 ± 1.3
Phase 4	3.9 ± 0.6	4.3 ± 0.9	3.9 ± 1.1
Phase 5	3.5 ± 1.2	3.9 ± 1	4.5 ± 0.8
Phase 6	3.9 ± 0.8	3.8 ± 1	4.6 ± 0.7
Overall mean	**3.7 ± 0.4**	**4 ± 0.2**	**4.1 ± 0.5**

Table 6.7: Descriptive statistics across process phases, second iteration (Mean ± SD) of 8 teams × 6 phases = 48 responses.

Table 6.8 and Table 6.9 reports the statistical distribution of student evaluations in the final individual course survey (N=16 out of 33 enrolled students). Given the small sample size (N=16), each participant accounts for 6.25% ((1/16) * 100, i.e., +/- 0.06 of the total) in this second iteration. It shows that direct engagement with teaching staff is the highest-rated dimension, with 50.0% of respondents reporting excellent engagement. Students also confirmed a strong structural understanding of the course, reporting high clarity regarding the general process and next steps. The structured guidance provided by mentoring worksheets was similarly validated, showing remarkable cross-student consensus.

In terms of activity effectiveness, mentoring sessions were rated consistently high, with 87.5% of respondents categorizing them as either "very" or "extremely helpful". Tutorials were rated more moderately, with a predominant mode of "somewhat helpful" (43.75%), reinforcing the phase-level finding that tutorial content represents a primary aspect for refinement. General CP engagement yielded the highest dispersion among all measured dimensions (SD=1.7), spanning ratings from Poor (25.0%) to Excellent (43.75%). This variance translated directly into perceived meeting effectiveness with CPs, showing how heterogeneous levels of external stakeholder availability and commitment can impact a core structural pillar of the CBL course experience.

Dimension	Poor	Fair	Okay	Good	Excellent	Mode
Level of engagement in course	1 (6.25%)	0 (0%)	1 (6.25%)	9 (56.25%)	5 (31.25%)	Good
Clarity of next steps	0 (0%)	1 (6.25%)	1 (6.25%)	7 (43.75%)	7 (43.75%)	Good/ Excellent
Clarity of general process	0 (0%)	0 (0%)	2 (12.5%)	9 (56.25%)	5 (31.25%)	Good
Engagement with teachers	0 (0%)	0 (0%)	1 (6.25%)	7 (43.75%)	8 (50.0%)	Excellent
Engagement with Challenge Provider	4 (25.0%)	2 (12.5%)	2 (12.5%)	1 (6.25%)	7 (43.75%)	Excellent
Teamwork with fellow students	0 (0%)	0 (0%)	5 (31.25%)	6 (37.5%)	5 (31.25%)	Good
Clarity of mentoring worksheets	0 (0%)	0 (0%)	3 (18.75%)	9 (56.25%)	4 (25.0%)	Good

Table 6.8: Statistical distribution of the students' evaluation of course dimensions ($N = 16$ out of 33), second iteration.

Activity	Not at all	Slightly	Somewhat	Very	Extremely	Mode
Tutorials	0 (0%)	2 (12.5%)	7 (43.75%)	6 (37.5%)	1 (6.25%)	Somewhat helpful
Mentoring sessions	0 (0%)	0 (0%)	2 (12.5%)	9 (56.25%)	5 (31.25%)	Very helpful
Meetings with CP	1 (6.25%)	3 (18.75%)	4 (25.0%)	2 (12.5%)	6 (37.5%)	Extremely helpful

Table 6.9: Statistical distribution of the students' perceived activity effectiveness ($N = 16$ out of 33), second iteration.

6.5.2 Qualitative findings

Qualitative findings for the second iteration were established through a hybrid thematic analysis combining an initial deductive baseline from Iteration 1 with an inductive analysis of participant interview transcripts, open-ended responses from bi-weekly phase surveys (Phases 1–6), open-ended responses from the final survey, and Miro process artifacts. This triangulation revealed three central thematic areas: (1) the transition from a binary "Structured vs. Open" framing to a multidimensional path matrix, (2) student perceptions of the CYOA-CBL framework regarding adaptive learning, autonomy, and structural tension, and (3) student evaluations of specific instructional tools, learning activities, and operational bottlenecks during the course period.

From "Structured vs. Open" to a Multidimensional Path Matrix.

Analysis of Miro boards revealed that while five out of eight teams maintained a consistent primary pathway throughout the semester, three teams exhibited significant domain shifts.

Visual mapping demonstrated that the traditional binary categorization of "Structured versus Open" CBL [11] was insufficient to describe student navigation. Notably, no similar figure existed in the first iteration; in this cycle, richer and more detailed data was collected through the use of Miro and a phase-by-phase analysis of each student group's activities. Consequently, teams distribute themselves across two spectra defined by two distinct axes, forming a four-quadrant matrix that categorizes team behaviors (see Figure 6.5). The matrix is defined by two intersecting axes representing continuous spectra:

Process trajectory (from linear to dynamic): this axis describes the directional stability of the team. On one end, **Linear** teams follow the phases sequentially without major deviations. On the other, **Dynamic** teams show high adaptability, iterating on previous phases or radically changing their project direction (e.g., from Tech to Policy) in response to friction or new insights.

Activity scope (from specialized to integrative): this axis describes the breadth of disciplinary integration within a single phase. **Specialized** teams focus deeply on a single domain (e.g., addressing only the technological aspects of the challenge). Conversely, the **integrative** end captures teams that combine multiple perspectives (Business, Policy, Tech). Since the course design does not prescribe a specific mode of integration, this category encompasses a spectrum of complexity [108]:

- Multidisciplinary: drawing on knowledge from different disciplines but keeping them distinct;
- Interdisciplinary: analyzing, synthesizing, and harmonizing links between disciplines into a coordinated and coherent whole;

These axes represent a continuum. While teams may drift towards the center or fluctuate during the semester, the intersection of the axes creates four archetypical behaviors that help explain the different "adventures" experienced by the students:

- Linear-integrative: teams in this quadrant maintain a steady forward progression but ensure every phase is analyzed through multiple lenses.
- Dynamic-specialized: teams in this quadrant tend to dive deep into a specific domain but are forced to change path radically when they encounter constraints.

- Linear-specialized: these teams choose a specific domain and follow the phases sequentially without major deviations. While efficient, this approach may sometimes reflect a "survival mode", where teams minimize ambiguity and exploration simply to meet the course requirements without exploring the open-ended challenges proposed by the course.
- Dynamic-integrative: this represents the most complex archetype. These teams constantly iterate on their process while simultaneously juggling many dimensions of the challenge. While this approach fosters deep learning and adaptability, it can feel chaotic and requires high team maturity to manage without losing focus.

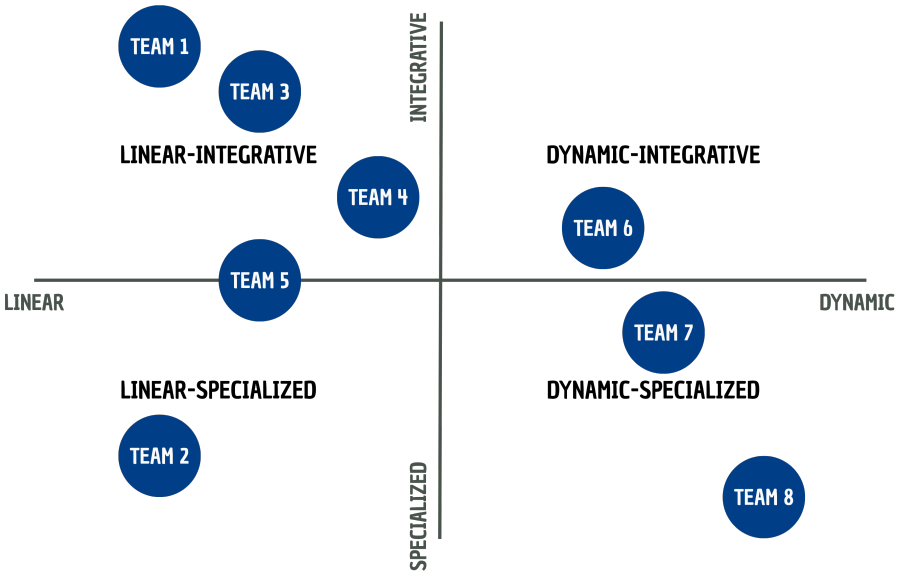


Figure 6.5: Two-dimensional spectrum showing student team process flows and scope approaches.

This matrix moves beyond evaluating whether teams were more "structured" or "open", illustrating instead how students leveraged their freedom. Team 1, for instance, exhibited a *Linear-Integrative* pattern; their Miro board showed steady phase progression where every stage combined business and policy dimensions. As Student 1 explained:

> "It was a bit of a hybrid, between business and maybe policy too[...] when we made the proposal for the solution, we proposed solutions that were more technological but also just policy-based [...] the whole process ran in parallel.".

In contrast, Team 8 represents a high degree of Dynamism and Specialization. Their journey was characterized by a distinct shift in domain. They started with a Specialized Tech focus but shifted completely to a Policy focus. Student 5 from Team 8 noted:

> "At the beginning, we thought we would focus heavily on the technological path because we preferred working directly with the software used by the company. In the end, this didn't turn out to be the case, so let's say the path shifted more towards a policy part. So from that point of view, it completely changed.".

Perceptions of CYOA-CBL: adaptive learning, autonomy, and structural tension.

The CYOA-CBL framework's flexibility remained a highly valued component of the course design. It was broadly recognized as a primary driver of student agency, professional confidence, and reduced performance stress. Working directly on real-world business challenges fostered strong ownership. Student 7 noted that "flexibility was one of the best aspects... it reduced pressure and encouraged exploration", while Student 10 emphasized that the general structure of CYOA-CBL allowed them to "go to whichever direction we wanted". Student 5 explicitly connected this autonomy to professional self-efficacy:

> "In my opinion, it was more complicated than a guided challenge, but at least [...] this freedom made us feel more independent, more confident in our choices, because we also felt important to the company.".

Students strongly commended the framework's capacity to support self-directed learning paths, noting that autonomy in communicating with external companies and structuring team workflows cultivated independence and project ownership. The six-phases approach proposed by CYOA-CBL was praised for providing a clear, practical rhythm that made open-ended challenges approachable.

This adaptive capacity extended to final deliverables, where groups personalized report structures to match their challenge's specific needs rather than adhering to rigid templates. As Student 8 observed, being able to modify chapters of the final deliverable of the course allowed the team to be "free to adapt" based on challenge provider needs.

However, qualitative accounts also highlighted intra-team divergences regarding the optimal balance between guidance and autonomy. This divergence was shown within Team 1, where two members held opposing views on the structured phases. Student 2 perceived the phase requirements as an artificial constraint on real-world problem-solving:

> "There was this gap between [...] this real world problem [...] and then on the other side we had to do this step and this step [...] which not necessarily fit to the problem... to have more flexibility in this regard I think would be helpful to not have this structure.".

In contrast, Student 1 viewed the exact same structural phases as a necessary safeguard: "There was a lot of freedom. [With more freedom] there would have been total anarchy".

This divergence suggests that CBL can be perceived in different ways and the CYOA-CBL framework is aligned to the flexible characteristic that we were looking for.

Analyzing open-ended phase surveys revealed how operational friction shifted across the project lifecycle. During phases 1–3 teams struggled to align team members, establish clear workplans, and resist the temptation to jump prematurely to solutions before fully exploring the problem space. In phases 4–5 groups encountered substantial difficulties recruiting interview participants, distributing questionnaires, and securing responses. In Phase 5, delayed data collection directly impeded business modeling and synthesis, forcing teams to execute pivot strategies or construct contingency plans. Finally in phase 6 the challenges centered on filtering extensive research data down to a prioritized, viable solution and rehearsing final pitch presentations under time constraints.

Evaluation of instructional tools, learning activities, and operational bottlenecks.

Evaluations of specific instructional components revealed clear distinctions in utility across mentoring sessions, tutorials, and tracking tools:

Mentoring vs. Tutorials: mentoring sessions remained the most highly valued scaffold, providing actionable feedback, progress checks, and direction during periods of ambiguity. Mentoring was recognised as the critical scaffold sustaining students autonomy; students emphasized that clear worksheets and actionable, constructive feedback during mentorship provided valuable direction whenever groups experienced disorientation or internal disagreement. Conversely, tutorials exhibited diminishing utility as the semester progressed. While initial sessions effectively framed upcoming phases, later tutorials felt repetitive or disconnected from heterogenous group-work timelines. Some participants noted tutorials acted as a useful "trigger" for next steps or provided clear reporting outlines (Student 7, Student 10), but advanced teams felt forced to repeat work already completed independently. Participants recommended restructuring tutorials to be more dynamic, optional, or tightly integrated

into mentoring hours.

Miro as a process tracker: while Miro boards proved valuable for research mapping, student feedback was mixed. Student 1 acknowledged the visual utility ("we could see our next comes this phase"), but noted that logging activities felt like an external administrative activity separate from daily workflows. The tool was perceived as an external administrative task, suggesting a need for better integration into the daily process.

Midterm presentation: introduced in Iteration 2 to address the long-semester pacing gap identified in Iteration 1, the midterm presentation was seen as a formal milestone. Although it introduced performance pressure, students recognized it as a necessary alignment point. Student 6 remarked:

> "I think that was the best part to get feedback early. We didn't really know what we were doing yet, and the feedback helped us realign.".

Additionally, peer presentations enabled cross-team benchmarking, allowing groups to compare their work with one another and learn from collective feedback (Student 2).

Challenge provider: throughout all project stages, passive or unresponsive challenge providers represented a primary external bottleneck. Communication delays from CPs caused initial disorientation and forced teams to lag behind scheduled milestones. However, instructional intervention and peer support encouraged teams to take control of their own challenge direction, turning stakeholder friction into a practical exercise in self-management and adaptive problem-solving.

6.6 Discussion and conclusions

This study evaluated the implementation of the "Choose Your Own Adventure in Challenge-Based Learning" (CYOA-CBL) framework across two iterations of a graduate-level and mandatory curricular course in Innovation and Entrepreneurship for computer science students. By combining quantitative tracking data (phase and final surveys) with qualitative insights (semi-structured interviews, students artifact analysis, and observational notes), this research explored how an adaptive scaffolding structure can address some of the current challenges with the development of CBL courses in computing education.

6.6.1 Cross-iteration and triangulation of mixed methods data

Despite the relatively small sample size, descriptive survey results indicated consistently positive evaluations across all measured dimensions. However, the findings should be interpreted cautiously and should not be considered statistically significant without further inferential analysis. Across both cohorts, mentoring sessions were rated as the most effective scaffold (Iteration 1: M=4.2, SD=0.2; Iteration 2: M=4.0, SD=0.2), with over 80% of students in final individual survey rating them as "very" or "extremely helpful". Qualitative feedback revealed that mentoring enabled teams to: 1) verify project direction and pivot when necessary; 2) strategically plan actionable next steps rather than merely review past work; and 3) being efficient thanks to real-time feedback that allowed teams not to get stuck and to move forward in the process.

Conversely, tutorials yielded lower and more dispersed satisfaction scores (Iteration 1: M=3.9,SD=0.3 and Iteration 2: M=3.7,SD=0.4). Triangulation with qualitative data explained this divergence and suggests that the CYOA-CBL framework addresses the "heterogeneity problem" of our mandatory engineering course. We observed a clear dichotomy in student needs: students with lower motivation or higher disorientation regarding open-ended problems relied heavily on the provided structure and pre-defined activities, while other teams used the framework's flexibility to deviate from the standard structure. While highly autonomous teams found generic tutorial exercises redundant with their independent work, less-motivated or struggling teams leveraged tutorials as essential co-working spaces to advance their project tasks.

In both iterations, student perceptions of "clarity of next steps" had a good evaluation (Iteration 1: M=4.2, SD=0.3 Iteration 2: M=4.1, SD=0.5). Rather than experiencing peak disorientation at the start, as commonly reported in standard CBL literature, students maintained high initial clarity, experienced a moderate dip during intermediate execution phases (Phases 2–4, where teams faced field research bottlenecks, survey recruitment challenges, and external stakeholder ambiguity), and reached peak clarity during final solution phase of the course.

Granular artifact tracking via Miro boards in Iteration 2 provided a key insight into team dynamics. Rather than a simplistic "Structured vs. Open" dichotomy, student path can be defined by a two-dimensional matrix defined by Process Trajectory (Linear vs. Dynamic) and Activity Scope (Specialized vs. Integrative). This taxonomy demonstrates that performance is not tied to a single ideal path: linear-specialized teams operated with high efficiency, while dynamic-integrative teams successfully managed broad perspectives, provided their dynamic pivots remained structured.

6.6.2 Final evaluations

Below are the answers to the secondary research questions of this chapter and study.

SRQ1: Is it possible to design a CBL course in computing education that is not disorienting for students who need more guidance, but still flexible for those who want to explore open-ended challenges?

The evaluation of CYOA-CBL suggests that structure and openness are not mutually exclusive, but can coexist within a unified course architecture. The six-phase structure and standardized mentoring worksheets provided "guardrails" that prevented disorientation. Students explicitly noted that having predefined phases reduced cognitive paralysis and performance anxiety without constraining their creative choices. At the same time, the framework granted teams complete agency over their analytical depth, methodology, and scope. Highly autonomous teams expanded section and course requirements, integrated primary field data, and pursued personalized trajectories without instructor overhead, indicating that an adaptive scaffold can support students needing guidance while providing open space for ambitious exploration.

SRQ2: Can the CYOA-CBL format serve as an effective response to the need for adaptive learning pathways in challenge-based environments?

The CYOA-CBL framework offers an effective scaffold for self-regulated and adaptive learning. Data from both iterations showed that teams naturally adopted non-linear pathways without requiring direct instructor intervention. In Iteration 1, 9 out of 12 teams dynamically adapted their path at least once during the semester.

In Iteration 2, teams distributed themselves across four distinct archetypes (Linear-Integrative, Dynamic-Specialized, Linear-Specialized, and Dynamic-Integrative), dynamically pivoting (e.g., shifting from a technological focus to a policy-oriented strategy) based on their preferences, attitudes, motivations and challenges. The CYOA-CBL structure thus serves as a flexible "container" that organically absorbs real-world challenge ambiguity and deals with different types of students in a normal mandatory and curricular course of computer science students.

We observed how students could define their own experiences and processes, personalizing their course and approaching challenges from angles closer to their interests. Students stated that CYOA-CBL provided them with the freedom to be creative while maintaining a structure to avoid losing direction and becoming overwhelmed by the complexity of the challenges. Taken together, these studies provide consistent evidence of how CYOA-CBL may contribute to fostering an empowering learning environment by offering appropriate instructional and support mechanisms

that enable learners to personalize their learning experiences in accordance with their individual needs and objectives.

SRQ3: How is the CYOA-CBL model perceived and interpreted by students with different dispositions toward learning, structure, and autonomy?

Student perceptions of the CYOA-CBL framework were deeply mediated by their individual and collective dispositions toward autonomy, intrinsic/extrinsic motivation, and tolerance for ambiguity. Qualitative data shows that learners saw CYOA-CBL as an empowering framework. They valued the freedom to communicate directly with external stakeholders, tailor final deliverables, and select challenge paths, explicitly linking this autonomy to increased professional confidence and self-efficacy. For students more inclined to traditional learning, the framework's structured worksheets, bi-weekly mentoring, and predefined phase goals served as a safety nets. These elements allowed the students to maintain steady progress without feeling overwhelmed by the open-ended nature of real-world challenges. Qualitative evidence showed that even within the same team, members interpreted the exact same structural phases differently - one viewing them as a "guided freedom" against "total anarchy", and another as a mild constraint on real-world problem solving. This confirms that CYOA-CBL can operate as an adaptive environment capable of catering to contrasting student dispositions and attitudes simultaneously.

6.6.3 Conclusions and future work

The findings of this two-year study offer some insights for educators implementing Challenge-Based Learning in computing and engineering curricula.

First, course design should prioritize flexible team mentoring over traditional frontal lectures. Tutorials should not be viewed as mandatory instruction for all, but as access points to the "minimum viable competency". Future iterations should consider treating specific tutorials as optional resources for getting the basics and being on track and offering "advanced tracks" for teams that have already mastered the basics.

Second, qualitative observations highlighted a pronounced divide in student mindsets. While intrinsically motivated students embraced open-endedness as an empowering opportunity, students viewing the compulsory course purely as a bureaucratic requirement exhibited high ambiguity aversion and passive engagement.

We observed a "surface attitude" in students who treated the course purely as a bureaucratic requirement. Since the course was compulsory, they entered with a passive

mindset. This was confirmed by low pre-course information seeking and acceptance of the course as a requirement rather than a choice. Students said: *"The course was mandatory... So I had to take it"*. Similarly, another said: *"I didn't choose it... it was automatic"*. This attitude tends to see the course as a task to be completed, minimizing impact on personal time outside the classroom. Some students want to do *"everything in class and after that we are free"*.

This contrasts sharply with students possessing a "growth" attitude, such as an Erasmus student who had the opportunity to voluntarily choose the course, describing it as a *"fun challenge"*.

There is also a strong "fear of ambiguity" among some students, particularly those from technical backgrounds who lacked the mental models for self-direction.

Although this student evaluation was based solely on interviews and our observations of team dynamics, rather than formal assessments, it highlighted significant differences among student cohorts in this mandatory computer science course, revealing distinct attitudes, motivations, preferences, and learning approaches. Most CBL literature implicitly assumes a cohort of highly motivated, "elite" students. There is a need for pedagogical structures that can support students who fall across the entire spectrum of motivation — from the risk-averse, grade-oriented student to the adventurous, intrinsically motivated explorer. These insights can help the computing education community better understand students and inform tailored support strategies. Future research will continue the investigation about the correlation between intrinsic/extrinsic motivation and student choices throughout the courses.

In relation to RQ2 and RQ3, these findings suggest that the CYOA-CBL framework serves as a structured tool for teachers to organize and manage the inherent ambiguity of CBL, maintaining pedagogical control over the course while empowering students to adapt their learning paths to their individual motivations and readiness.

Chapter 7

Validating the CYOA-CBL framework: an implementation in a short and extra curricular course

The previous chapter provided empirical support for the effectiveness of the CYOA-CBL framework within a curricular, semester-long mandatory course. In that context, the framework addressed the heterogeneity of computer science students, balancing the need for structure with the desire for autonomy, and proved manageable for the teaching staff. However, the third objective of this thesis (O3) is to make CBL replicable and flexible in different contexts. To test whether CYOA-CBL can serve as a viable solution, the framework must also demonstrate its robustness beyond the traditional semester format.

This chapter serves as another test for the flexibility of the CYOA-CBL. It investigates whether the pedagogical integrity of the framework can be maintained when applied to a significantly different educational context: a short, intensive, and extracurricular learning experience.

Implementing CBL in short timeframes presents difficulties. The open-ended nature of challenges typically requires extended periods for exploration, definition, and iteration that are not available in condensed courses [33]. Consequently, the adaptation of CBL designs across compressed timelines remains a challenge that is not much explored in current literature. This chapter addresses this gap by analyzing an intervention carried out within an interdisciplinary initiative promoted by the ECIU Alliance. The study involves a four-week blended activity (one week in-person, three weeks online) where Master's students addressed a challenge related to the social benefits of the sport of orienteering.

By shifting the focus from a long-term, mandatory course to a short-term, voluntary experience, this chapter aims to show that the CYOA-CBL framework can act as a flexible scaffolding that can be condensed and rapidly reconfigured to support micro-credentials and intensive workshops, confirming its potential as a scalable solution for diverse learning environments.

The contents of this chapter are based on the following publication:

- **Strategies for Implementing Challenge-Based Learning in Short Courses: Developing Professional Skills Through Challenges**
  J. Lucchetta, S. Turrini, M. Marchese, and L. Angeli
  Published in Proceedings of the 57th ACM Technical Symposium on Computer Science Education V.2 (SIGCSE TS 2026), February 18–21, 2026, St. Louis, MO, USA. ACM, New York, NY, USA, 2 pages, doi: 10.1145/3770761.3777287.

7.1 Pedagogical context

The adaptation of CBL designs across different educational contexts remains challenging and underexplored in practice [83]. While the previous chapters shows the effects of the CYOA-CBL framework in a full-semester setting, this study investigates whether the same approach could be effectively adapted into a four-week extracurricular activity while maintaining its pedagogical integrity. The intervention took place within an extracurricular activity organized at the University of Trento as part of an initiative promoted by the ECIU Alliance, a consortium of 13 European universities involved in sharing innovative learning activities and focusing on CBL approaches. The activity was open to students from various disciplines, although its learning objectives focused on strategic planning, teamwork, and effective communication, aligned with the skills and dispositions identified as essential for computer science professionals [120]. The activity involved Master's students and it awarded 3 ECTS credits. Participants came from mixed academic backgrounds and enrolled voluntarily by submitting an application and a letter of intent. The four-week program included one week of in-person activities followed by three weeks conducted online. A total of 20 students took part, organized into four teams of five members. The challenge was proposed by Park World Tour Italia Orienteering Club, as orienteering is known to foster transversal competencies such as problem-solving [76]. Students were asked to engage with the topic of orienteering and identify social benefits that the sport and the club could generate beyond athletic performance. The challenge was co-designed by the club's management in collaboration

with the teachers responsible for developing and implementing the activity. We collected anonymous individual feedback at the end of the course and group feedback after each phase of the process through short open-ended questions. This dual-level feedback approach allowed us to capture both personal reflections on the learning experience and team-based insights of the CBL process.

7.2 Methodology

To adapt the CYOA-CBL framework to the short duration of the activity, we condensed the six phases into two main stages (see Figure 7.1): three phases were conducted during the in-person week, while the remaining three phases were completed online over the following three weeks.

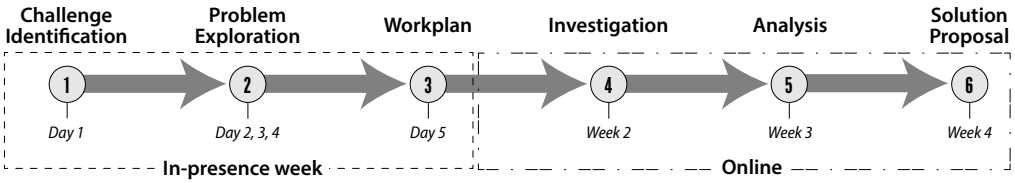


Figure 7.1: The adaptation of the CYOA-CBL framework for short-duration activities.

We conducted five mentoring sessions: three in-person during the first week and two online in the subsequent weeks. The students particularly appreciated the personalized feedback provided by mentors along the process. The so-called "mentoring worksheets" were used only to prepare the online mentoring sessions and support structured progress. In contrast, during the in-person week, mentoring sessions were intentionally less structured to allow more open discussions based on each group's progress. The so-called "tutorials" of the CYOA-CBL framework were maintained only during the in-person week, and no new content was introduced during the online phase, allowing participants to focus entirely on challenge development. Additionally, students attended inspirational lectures delivered by experts in orienteering, sports, and technology, and they also had the opportunity to experience orienteering firsthand through two practical sessions using maps and compasses. Compared to the curricular course, we leveraged Miro as a digital collaboration platform to facilitate coordination and communication among team members. Finally, the final deliverable was simplified to a presentation of the team's proposed solutions and reflections, since evaluation was conducted on a pass/fail basis.

7.3 Discussion and future work

The key adjustments in this short CBL experience, compared to the curricular course, were primarily related to time constraints and the balance between in-person and online activities. The division of phases was designed to begin the challenge in person, allowing teams to meet, interact with the challenge provider, and conclude the first week with a defined work plan, before continuing online with clear goals for each week. However, feedback revealed that students would have preferred the opposite order: starting online and concluding the challenge in person. This insight suggests an interesting direction to explore in future iterations.

Weekly mentoring sessions proved crucial in maintaining group engagement and ensuring progress, particularly within the short timeframe. In condensed CBL implementations, frequent checks help prevent students from feeling lost in the ambiguity of open-ended challenges. Even in this short activity, mentoring worked very well, and these structured and regular feedback moments were highly appreciated by students across different contexts. Similarly, a well-defined structure was valued by participants and proved essential to support them through this intense CBL experience.

A limitation of this implementation is the lack of an objective means to evaluate the gained skills. Due to the limited duration, it is difficult to achieve the same level of depth as in longer curricular courses. However, when viewed through the lens of micro-credentials, this type of short CBL experience can be particularly useful for developing specific competencies such as teamwork, communication, and critical thinking. Future work can also acknowledge the limitation of the small, self-selected sample size and seek to replicate the study with a larger, more diverse student population to enhance the generalizability of the findings. A potential future direction is to investigate how to design effective assessment methods for these transversal competencies within short-term implementations to provide objective metrics for skill acquisition. Future explorations will focus on implementing CYOA-CBL in hybrid learning environments and within the context of micro-credentials to further validate its adaptability and effectiveness.

Overall, this work indicates that CBL can be adapted to short extracurricular courses and that the CYOA-CBL framework offers a possible solution for developing flexible CBL experiences, ranging from long-term to short-term, and from online to in-person formats. By validating the framework's effectiveness under compressed timeframes and non-traditional settings, these empirical results help answer RQ2 regarding CBL adaptability across teaching contexts and achieve O3 by demonstrating

its replicability and flexibility.

Chapter 8

Discussion and conclusions

The objective of this dissertation is to navigate the evolving landscape of Computer Science education by identifying strategies to prepare students for Challenge-Based Learning (CBL), making it more manageable for teaching staff, and ensuring it is flexible and replicable across diverse contexts. By achieving these core goals, we aim to facilitate a wider adoption of CBL. Consequently — given that CBL inherently stimulates transversal competencies in CS students — this work ultimately contributes to addressing the broader challenge of computing education: equipping graduates not only with technical proficiency, but also with the key transversal skills and professional dispositions demanded by the professional sector.

As explored in Chapter 2, active learning strategies have emerged as one of the most effective pedagogical response to this need. Among these, Challenge-Based Learning (CBL) stands out for its ability to immerse students in authentic, real-world challenges. However, despite its potential, the widespread adoption of CBL in standard engineering curricula is often hindered by some barriers [83]. In this work, we specifically addressed three barriers:

- Barrier 1, student readiness and motivation. CBL courses are frequently the cause of student frustration [32].
- Barrier 2, necessary resources and scalability. The difficulty of implementing resource-intensive methodologies in large, heterogeneous cohorts with few resources [83].
- Barrier 3, structural adaptability and design tensions. The tension between the openness required by CBL and the structure needed to prevent students' disorientation [11].

To tackle Barrier 1 and meet O0 of this dissertation, we propose "Tech Battles" (Chapter 4), a preparatory activity designed to train the "Active Learning mindset" in a low-stakes environment. To address Barriers 2 and 3 and meet O1, O2 and O3, we developed the "Choose Your Own Adventure in Challenge-Based Learning (CYOA-CBL) framework (Chapter 5), a novel architecture that redefines the open/structured trade-off as a student-led choice. This framework was validated across two iterations of a mandatory curricular course (Chapter 6) and tested in an intensive short course (Chapter 7), demonstrating that adaptability can be one of the key to scaling CBL across diverse educational contexts.

8.1 Addressing the Research Questions

To provide a comprehensive synthesis of the contributions of this doctoral dissertation, this section directly answers the three core Research Questions (RQs) established in Chapter 3. The conclusions integrate empirical findings and theoretical reflections gathered across the different interventions during the doctoral years.

RQ1: How can preparatory teaching methods be deployed to prepare computer science students to deal with the complexities of active learning?

This question was formulated to address the student friction and anxiety frequently caused by the transition to non-traditional, active learning methodologies [89, 81, 101, 38]. Prior research [33, 104, 103, 89] has highlighted the difficulties students of technical domains face when suddenly confronted with open-ended, highly ambiguous learning environments, such as those in a CBL course. To lower this resistance and cultivate positive attitudes toward active learning approaches, this doctoral thesis presents the design of the "Tech Battles", a preparatory active learning intervention centered on structured in-class debates grounded in Science Fiction (Sci-Fi) short stories.

Prior literature suggests that debates effectively foster transversal competencies [2, 16]. Our empirical qualitative findings suggest that grounding debate scenarios in speculative Sci-Fi narratives — rather than dense technical specifications or artificial scenarios created from scratch by instructors — can be used effectively with CS students, and help students distance themselves from prior biases. By detaching argumentation from immediate technical fact-checking, the method removes the fear of "not knowing enough" technical details, and detaches students from ideological positions. The design of Tech Battles creates a low-stakes environment where students feel safe to express ideas, formulate arguments, and challenge opposing views without fear of academic penalty or peer judgment. Without the cognitive load of technical validation, students

can focus their full attention on exercising core transversal competencies, including critical thinking, public speaking, structured argumentation, and multi-perspective analysis - which subsequently prove relevant in more complex active learning contexts.

Furthermore, by leveraging speculative scenarios, narrative priming shifts student perceptions away from passive learning expectations, thereby mitigating potential "pedagogical shock". This propaedeutic and preparatory phase fosters an active mindset and enables progressive acclimatization across the curriculum, prior to encountering the complexity and ambiguity of full-scale CBL courses. Experiencing low-stakes collaborative debates builds communication confidence and decreases resistance, preparing students to engage constructively in future challenges.

Therefore, in answering RQ1, we showed a possible teaching method that can foster confidence and minimize learning resistance by implementing narrative-driven, low-stakes debate structures that separate transversal competencies practice from technical evaluation. By using speculative Science Fiction as a preparatory bridge, educators reduce cognitive anxiety before introducing complex methodologies.

RQ2: How can CBL be made more adaptable to a greater variety of student motivations, teaching contexts, and institutional resource constraints?

This question was formulated to address a structural tension in Challenge-Based Learning (CBL), where the traditional balance between open-ended student autonomy and structured guidance often creates friction for learners with low ambiguity tolerance while placing high demands on teaching resources [11]. Previous research in active learning has recognized the benefits of authentic, real-world problem-solving connected with CBL [50, 33]. However, a critical gap remains regarding how CBL frameworks can be operationalized across heterogeneous student cohorts, varying course formats, and limited mentoring capacity, which tends to be even more limited in a Computer Science department that may have little staff specialising in non-technical topics. The following analysis and discussion synthesize empirical results across two studies presented in Chapter 6 and 7.

The empirical findings demonstrate that the "Choose Your Own Adventure in Challenge-Based Learning" (CYOA-CBL) framework offers a structural approach to address the traditional trade-off between structured and open CBL by moving this choice from the teacher to a student-led choice. Student cohorts naturally exhibit diverse levels of prior experience, self-efficacy, and ambiguity tolerance. Rather than imposing a uniform structure, CYOA-CBL enables student teams to position themselves on a spectrum between structured and open paths. These results align

with Scaffolding Theory [119], confirming that flexible instructional support prevents cognitive overload in less confident teams while preserving room for advanced innovation among self-directed learners.

Regarding context adaptability, the empirical validation highlights that CYOA-CBL seamlessly transfers across contrasting educational settings and timeframes. The framework was evaluated in two distinct environments: a mandatory, 6-ECTS semester-long Master's course and an intensive, 4-week challenge. Across both settings, the modular six-phase architecture maintained operational consistency and ensured learning objective alignment regardless of course duration, institutional constraints, or students profiles. This structural flexibility demonstrates that CBL can be effectively scaled across formal curricular subjects and short-term extracurricular initiatives alike.

In terms of resource constraints, the study reveals how CYOA-CBL mitigates instructor overload: typical CBL implementations frequently encounter scalability bottlenecks due to the excessive coaching required to guide teams through unstructured challenges. CYOA-CBL addresses this by substituting continuous direct supervision with a six-phase structure, with a defined number of mentoring sessions and worksheets as checklists for students and explicit phase-transition criteria.

To conclude the answer to Research Question 2, CBL can be adaptable to diverse students, contexts, and resource constraints by implementing a scaffolded framework that modularizes course progression, offers flexible choices to accommodate student heterogeneity, enables cross-context execution, and optimizes instructional resources.

RQ3: How can teachers adapt CBL to let students fine-tune their learning experience without trading off control over the course?

This question was formulated to investigate the mechanisms that resolve the operational tension in Challenge-Based Learning (CBL), where instructional oversight and student autonomy have traditionally been treated as opposing forces. In conventional CBL environments, giving students total freedom over project directions often compromises course predictability, complicates evaluation, and inflates teaching staff workload. Conversely, imposing rigid institutional guidelines risks dampening student engagement and triggering learning resistance. The following analysis synthesizes theoretical reflections and empirical findings to demonstrate how a scaffolded framework reconciles systemic instructional control with student empowerment.

The empirical evidence reveals that the "Choose Your Own Adventure in Challenge-Based Learning" (CYOA-CBL) framework achieves a balanced combination by separating structural course design from challenge-level decision-making. Instructors

maintain systemic control through a fixed six-phase linear workflow, structured evaluation checkpoints, and mandatory milestone deliverables. The framework is proposed for teachers as a tool to organize the inherent ambiguity of CBL. Its boundaries allowed educators to maintain academic oversight without limiting students in their open-ended exploration required by CBL. By establishing macro-level constraints, teachers can monitor student progress and coordinate logistics across large cohorts.

Concurrently, the framework empowers student teams to self-regulate their learning trajectories by choosing between structured and autonomous paths. Teams can fine-tune their learning experience along a multidimensional spectrum, adjusting process depth, technical complexity, and project scope according to their self-efficacy and team objectives. These findings align with Self-Determination Theory [92], which asserts that satisfying fundamental psychological needs for autonomy, competence, and relatedness significantly enhances intrinsic motivation. Thanks to the empirical study presented in Chapter 6, we could observed that highly motivated teams leverage open pathways to pursue deep exploration, while less confident teams utilize structured options as a safe foundation, satisfying the course requirements without suffering from choice paralysis or structural ambiguity.

Furthermore, this model effectively minimizes student friction within compulsory academic settings. In mandatory courses, student motivation is rarely uniform; cohorts have a mixture of intrinsically motivated learners and extrinsically driven students focused primarily on course completion [91]. CYOA-CBL accommodates this heterogeneity by providing a scaffolded safety net that guarantees academic success for guided teams while supporting the unlocking of autonomous paths for self-directed teams. By aligning instructional support with student readiness, the model prevents cognitive overload, reduces resistance in mandatory and active learning courses, and preserves overall educational quality.

To conclude, a scaffolded CBL approach can successfully grant teachers structural control while empowering students to tailor their learning experiences. By allowing student teams to self-regulate their journey within a secure scaffold, CYOA-CBL proposes a possible solution for accommodating students with diverse learning dispositions, self-efficacy levels, and motivational states.

8.2 The crucial role of the Challenge Provider

During our research on CYOA-CBL in the curricular course proposed in Chapter 6, we noticed that the success of a CBL experience is also dependent on an external

factor: the Challenge Provider (CP). The literature emphasizes the importance of the CP in motivating students by providing a bridge to the "real world" [68]. Indeed, by introducing authentic challenges, the CP anchors the experience in contextual and situated learning. Each challenge represents an isolated, unique problem space where solutions are deeply context-dependent, requiring students to immerse themselves directly in the real-world environment of the challenge. This contextual nature can introduce ambiguity and adaptation hurdles for learners encountering unfamiliar domains [87]. Although navigating such unfamiliar contexts can introduce ambiguity and adaptation hurdles for learners, grounding the learning process in authentic, real-world challenges drastically improves student engagement [87].

Our empirical findings from the study described in Chapter 6 strongly confirm this. We observed a direct correlation between the level of the CP engagement and student motivation. When CPs were disengaged, the impact on student morale was severe. As Student 7 (Iteration 2) reported:

> "[The CP] was slow to respond to emails, which was discouraging. We felt like we were trying to help solve a problem, but couldn't even communicate properly with the person who proposed it.".

Similarly, Student 6 (Iteration 1) identified the CP's absence as the root cause of their team's failure:

> "I think the base of this situation was the lack of involvement of the case provider, but because of that, there was another lack of motivation between all the people in the group.".

Conversely, active engagement acted as a powerful motivator. Student 10 (Iteration 2) noted:

> "I liked the fact that we were in contact with companies. I think it gives us an exposure to what is really happening in the world other than the university environment.".

Students were also aware of the disparities in CP involvement across different teams, comparing their experiences with peers. As Student 6 noted, seeing other groups visit their provider and progress faster due to frequent interactions highlighted the disadvantage of having a passive CP.

8.2.1 Transforming external actors into Challenge Providers

Recognizing this critical dependency to an external actor not controlled by the staff of the course, we formalized a process to ensure high-quality engagement from external partners. This contribution was presented at the International CBL Conference 2025:

- **How do external actors become Challenge Providers in a Challenge-Based Learning curricular course in higher education?**
  S. Turrini, J. Lucchetta, L. Angeli, and M. Marchese,
  Published in International CBL Conference - CBL 2025, Eindhoven, The Netherlands, doi: 10.5281/zenodo.15675039

One of the main features of Challenge-Based Learning (CBL) is that the Challenge Provider (CP) is an actor external to the teaching setting. Often, this actor belongs to a different organisation becoming what we refer to as an external stakeholder. In the context of higher education institutions, we define external stakeholders as organizations whose primary activities occur outside academia but who have interest in the institution's objectives and activities. However, in some cases, the CP may not be a stakeholder but simply an external actor (EA); for instance, a teacher from the same university might propose a challenge related to a personal project. For this reason, we consider the essential requirement for being a CP to be coming from outside the pedagogical setting, acting as a third party separate from both teachers and learners.

Over the years, we have noticed that the success of Challenge-Based activities and the quality of student learning are closely linked to how effectively EAs are transformed into CPs. However, to our knowledge, the current literature on CBL does not adequately cover the role of EAs within CBL, even if some contributions can be found [71, 36, 3, 42]. The presence of CPs in CBL courses is fundamental: through the intersection of open and real-world problems and educational activities, CBL can be presented as a pedagogical approach suitable for acquiring the knowledge, skills and dispositions that are essential for the 21st century.

This contribution is based on our experiences with a 6-ECTS mandatory curricular course designed for second-year Master's students in Computer Science (CS) who are following a curriculum that integrates CS with Innovation and Entrepreneurship (I&E), the same as the one described in Chapter 6. Since 2017, the course has adopted CBL, and every year involves from 4 to 7 EAs as CPs, and students ranging from 35 to 70.

A significant characteristic of this course is the presence of multiple CPs in each edition. In this regard, we observe interesting similarities and differences with the

model of multi-CBL presented by Ramírez-Cadena et al. during the 2024 IEEE Global Engineering Education Conference.

Identification and "first contact"

"First contact" can be challenging to establish. We have defined various strategies to employ when identifying EAs before the course begins. These include:

1. Leveraging formal networks of organizations involved in Innovation & Entrepreneurship (I&E) projects;

2. Partnering with local innovation hubs;

3. Utilizing personal contacts developed through previous collaborations;

Additionally, another interesting and feasible strategy (which we have not yet explored) could involve issuing a public call for EAs interested in engaging with the university.

The information package

In all the cases mentioned above, establishing a trust-based relationship between EAs and teachers is essential, with transparency and completeness of information as its foundation. Therefore, we have created an "information package" that facilitates "first contact". This package is a written presentation that outlines what a CBL course is, how it is structured, the learning objectives, and the staff involved. We also provide information about the profile of the students and the commitment required from them. We specify the types of challenges we are looking for and provide examples. Additionally, we clarify that challenges are not just tasks: each challenge should allow for broad thematic exploration of a specific problem. We also inform the EAs about the potential benefits of participation, as well as the commitments they would need to make. We usually ask the EAs to provide data/contacts, insights and internal perspectives from their organization, to participate in one of the initial course classes (challenges and CPs presentation), in one of the final appointments (oral exam for students), and to engage in some catch-up meetings with students (one meeting every two or three weeks) to ensure that the learning process is rooted in real life.

The Challenge Descriptor

The transformation culminates in the drafting of the "Challenge Descriptor". It is a template provided by the teachers in which EA can describe the challenge with the support of the designated teacher. The EA is required to provide some basic information regarding the name of the organization, the title of the challenge and some keywords that can summarize the problem at stake. Then, there are five important sections to fulfill:

- **Challenge context:** students should be able to gain a clear understanding of the EA. The EA should assume it is addressing an audience with minimal prior knowledge about it. To facilitate this, we provide the EA with a set of "guiding questions";
- **Challenge description:** students should understand why the EA wants to propose a challenge and, broadly, what the challenge is. The EA is free to express the challenge in any way it prefers, but we consider some elements quite helpful: a) clear relevance (challenges should represent "big ideas"); b) no obvious single solution (challenges should be open-ended); c) a call to action (challenges should prompt students to work on them);
- **Maximum number of teams:** the number of teams (4-5 students each) that can choose to deal with a specific challenge during the course (we avoid having more than 2 teams per CP to not overload it);
- **Expected outcomes:** some examples are a reflection report, a policy survey, a business analysis, a business model, go-to-market scenarios, an MVP, assess the business potential of a novel technology for application areas and/or markets;
- **(Optional) material for inspiration:** websites, articles, books, or any material that could get the students inspired about the challenge.

Between the "first contact" and the "challenge description", the EAs undergo a "transformation". In this phase, we frequently interact with them through phone calls, emails, online and in-person meetings. Obtaining a written "challenge description" marks the end of the preparatory phase of each challenge. Through this section we aim to show that to reap the benefits of CBL, one of the most relevant step that each institution needs to perform is to create a solid process of conversion of external actors to Challenge Providers.

8.3 Critical reflection on resources and mentoring

A finding that emerged with consistency across our studies is the fundamental role of mentoring. Students identified face-to-face feedback sessions as the most valuable component of the course, preferring them to traditional lectures.

This observation prompts a critical reflection on scalability and resources, particularly when comparing our implementation at the University of Trento with models at larger institutions, such as TU/e (Eindhoven University of Technology) where I spent three months of my research period. At TU/e, CBL courses often enroll over 500 students. To manage these numbers, the university employs senior students (Student Assistants) to act as mentors, as they are significantly more cost-effective than professors. These assistants undergo preparatory training and primarily support groups with organization and team dynamics rather than deep content expertise.

At the University of Trento, mentoring was conducted by professors and teaching staff. Students declared that this function was fundamental not only for process management but also for the specific content feedback received. This raises a research question for the community: *Can peer mentoring replace expert mentoring without diminishing the learning value? While the peer-mentor model allows for massive scalability (800+ students), does it offer the same depth of feedback?*

If students in our study valued the specific feedback of the staff, there is a risk that shifting entirely to student assistants might dilute the perceived quality of the education. Future research should investigate the trade-offs between "process mentoring" (scalable via peers) and "content mentoring" (requiring experts) with an A/B test within the same course, comparing these two types of mentors.

8.4 Limitations and critical reflections

While the individual empirical investigations presented in Chapter 4, Chapter 6, and Chapter 7 outlined specific operational limitations, this section provides a synthesis of the overall research limitations.

One characteristic of this dissertation is its primary reliance on qualitative data and analysis embedded within an action research design supported by descriptive quantitative statistics. While this paradigm was deliberately selected to capture the nuanced, highly contextualized dynamics of student self-regulation, team interactions, and instructional shifts, it entails methodological constraints.

Action research cycles prioritize iterative refinement within a live educational

ecosystem over strict variable isolation [5]. Consequently, the high ratio of contextual variables relative to participant numbers precludes traditional statistical generalization, meaning that the empirical findings reflect localized dynamics rather than generalizable principles. Furthermore, the data collection strategy relied heavily on student self-reflections, semi-structured interviews, and collaborative process artifacts. Although post-course interview timing and anonymization protocols were carefully implemented to mitigate evaluation pressure, self-reported data remain susceptible to bias and social desirability effects. Finally, as established in the research scoping (Section 1.2), this work evaluated framework feasibility, student process dynamics, and course manageability, but deliberately did not incorporate an assessment of long-term skill retention or standardized competence metrics.

The empirical interventions were conducted exclusively at the University of Trento, mostly within the Department of Information Engineering and Computer Science. Although the student body included a significant international demographic, the physical learning ecosystem, academic regulations, and culture remain specific to this European higher education context.

Moreover, the framework was evaluated primarily with Master's level Computer Science and ICT Innovation students, alongside motivated voluntary participants in the ECIU extracurricular module. As a result, the applicability, structural demands, and necessary scaffolding requirements of CYOA-CBL for first-year undergraduate students or non-STEM cohorts remain unexamined in this work and outside the scope.

Across all implementation cycles, I had a dual function as both primary investigator and active co-teacher and inevitably influenced the research. Consequently, while the empirical findings demonstrate that CYOA-CBL is manageable for teaching staff, this manageability reflects performance in an environment co-designed and actively facilitated by the framework's creator. The ease with which completely neutral, external instructors (who lack prior experience with the methodology) can adopt and sustain the framework remains a subject for future validation.

Active learning literature is densely populated with overlapping acronyms and conceptual frameworks, ranging from Problem-Based Learning (PBL) and Project-Based Learning (PjBL) to Case-Based Learning (CsBL) and Challenge-Based Learning (CBL), all broadly categorized under the umbrella of X-Based Learning (XBL) [9]. This semantic ambiguity creates indexing and literature-mapping challenges, as highly relevant insights from PjBL or PBL studies are frequently published as distinct, making keyword searches and citations difficult.

Finally, a critical reflection address the risk of pedagogical trend cycles within higher

education research. Higher education frequently experiences recurring cycles in which new active learning emerge, gain widespread prominence, and eventually transition or merge into newer paradigms. If CBL loses traction or evolves into a new pedagogical term, there is a structural risk that framework contributions tied strictly to the "CBL" label might lose relevance over time. To mitigate this risk, this dissertation does not lie in advocating for "CBL" as a rigid, static label. Rather, the contribution is in the structural principles of low-stakes preparatory skills and dispositions development, adaptable scaffolding and student-driven pathway regulation. These principles address more broadly friction points in student-centered education - such as ambiguity tolerance, cognitive overload, and teacher workload - making the findings lasting, robust, and applicable across computing education and active learning as a whole, regardless of future shifts in educational terminology.

8.5 Future directions

The work presented in this thesis opens several alternatives for future exploration.

8.5.1 Teacher-side evaluation and motivation tracking

While we have extensively validated the framework from the student perspective, the teacher's experience regarding the workload and the "adaptability" of the design process has been treated as a design intention rather than an externally validated metric. Future studies should assess the burden on educators. Furthermore, we aim to investigate the correlation between pre-existing student motivation and their path selection within CYOA-CBL. By employing personality tests or motivation tests like the Situational Motivation Scale [44] before the course begins, we could see which students will gravitate towards which path, allowing for even more targeted interventions.

8.5.2 CYOA-CBL as an iterative process

We propose a reflection on integrating iterative student delivery into CYOA-CBL. Currently, the framework moves linearly through phases. Incorporating iterative cycles where students submit drafts and receive feedback multiple times, similar to the Agile methodology common in software engineering [95] could enhance the learning process. This would introduce a reflective phase, providing students with opportunities to refine their projects further before the final deadline.

8.5.3 Combining CBL and sports

Finally, a major future direction involves testing the adaptability of our approach in interdisciplinary contexts that combine cognitive and physical engagement. We see research promise in evaluating the transversal competencies developed by STEM students by combining CBL and Sports, starting from the sport of Orienteering. This project aims to bridge the gap between academia and the labor market by leveraging the unique characteristics of sports like orienteering or other niche-sports. Some of these sports foster competencies like strategic planning, resource management, and rapid decision-making under uncertainty, all of which mirror the demands of the modern workplace [76]. To this end, we propose collaborating with sports clubs to design educational activities where students face challenges requiring both intellectual and physical navigation. The goal is to develop a validated pedagogical framework and a set of guidelines for integrating sports into active learning, ultimately enhancing graduate employability by fostering resilience and adaptability. This initiative also represents a strategic step towards extending the CYOA-CBL principles into Micro-credentials and hybrid learning environments.

Ultimately, through the insights gathered from student feedback, interviews, and course iterations, we have gained valuable perspectives on tailoring educational experiences to meet diverse learning needs. While more research is needed to fully address the gaps associated with active learning, we align with Doulgeri et al., who suggest that CBL shows promising benefits when integrated at the course or curriculum level [33]. The implications of CYOA-CBL extend beyond the boundaries of Computer Science education. By empowering students to define their own learning paths, we aim to build an educational model that not only serves CS and engineering students, but also cultivates the agency, resilience, and self-direction required for a broader range of students to navigate the complexity of the world.

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Appendix A

Paper A

Leveraging Science Fiction to Prepare Students for Tech Battles

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ABSTRACT

In the last decades, teaching methods in computing are shifting towards active learning. Among these, a notable case are debate-based classes which can be used to develop skills such as critical thinking which, are in high demand in the workplace. The choice of debate topic is a particularly controversial theme, since it can influence the students' motivation, experience, and understanding of the course's content. In this poster, we propose an evolution of a debate-based teaching methodology, called Tech Battles, to include the reading of science fiction short stories as a preparatory activity. The intervention takes place in an Innovation and Entrepreneurship course for computing students at the University of Trento, where science fiction can help students develop critical thinking about technology and innovation, but also aid them in understanding the debate's context, and ultimately enhance their learning. We conclude our reflections by exploring possible implications of this change, connecting it to existing traditions that leverage science fiction as a pedagogical tool.

KEYWORDS

debates; innovation and entrepreneurship; science fiction

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1 CONTEXT

The focus of most computing curricula tends to be centred on technical knowledge [4]. However, in the last years, the computing field and the related work environment have given increasing importance to competencies and attitudes (again, [4]). These skills are difficult to develop through traditional learning methods [5], leading to a rise in the adoption of active learning approaches.

Debates represent a particularly interesting case within active learning. In-class debates are commonly used in humanities and law, as they promote interaction between students and increase engagement. In the computing domain, however, while literature reports some examples as far back as 2002 [1, 10], examples remain rare. Alfor and Surdu [1] claimed that debates could help students develop skills such as synthesising information, self-directed learning, critical thinking, and verbal communication.

To achieve these gains, though, a key issue is the selection of the debate's topic. A good topic should encourage students to think and deepen their knowledge [1], but should also feature clear opposing sides, easing the students in understanding the distinct positions and drawing different perspectives [7]. Debate topics play an important role in engaging the students and, if they are not appropriate, may cause a loss of motivation [11].

In this contribution, we propose to use science fiction short stories as an aid to create debate topics, and as a preparation activity. We aim to provide a scaffold for the students' understanding of the debate topics, stimulate their curiosity, and ensure that they can get a grasp on the content as early as possible in the process.

2 PEDAGOGICAL CONTEXT

Our intervention takes place within a course called "Innovation and Entrepreneurship (I&E) Basics", taught at the University of Trento. The course teaches basics of innovation theory, entrepreneurial practice, and social impacts of computing, while developing skills such as clear presentation and critical thinking. The course involves first-year Master's computing students in a curriculum that includes a 30-ECTS "minor in I&E" while specialising in a technical subdomain such as Autonomous Systems. The course has been attended by groups as small as 20 students and as large as 180 but, since 2020, attendance has stabilised to around 40 students.

The course notably employs Tech Battles (Battles), a teaching method where two teams of 4–5 students debate opposed views

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on a socio-technical theme in the domain of technological innovation. Since their first appearance in 2013, Battles have evolved from historical case studies to discussions of fictional scenarios [3]. Battles have then been further adapted to make the exercise more structured [2], following a frequent request from the students.

Each Battle involves (1) a Battle preparation meeting; (2) the debate itself; and (3) a "Battle Report". The Battle preparation is a 1-hour meeting involving the two debating teams and the teachers, and is used to set each Battle's rules and scenario. Scenarios aim to build plausible alternative worlds, where the class can have a discussion free from their own prejudices [8]. The Battle, done in a 2-hour class slot, sees the teams debating each other, while the class acts as an active audience, asking questions and ultimately voting for the more convincing proposal. Finally, in the report, the teams synthesize their learnings and reconcile their positions.

The current structure, however, still presents a key weakness: students come to the Battle preparation meeting without knowing anything about the topic of the debate. This, we argue, is a missed opportunity in making the preparation meeting more focused. Furthermore, the creation of scenarios is so far reliant on the teachers' creativity, when fiction literature could provide an abundance of potential scenarios ripe for debate.

3 OUR PROPOSAL

In this contribution, we propose to better prepare students for the Battle preparation meeting through an activity where students read science fiction (SF) short stories. Suitable short stories can introduce students to the themes that they will address during their Battle with a modest time investment. By choosing relevant stories, teachers can "prime" the students' imagination, stimulate their curiosity, and enrol them in co-creating the scenario.

SF has a long tradition of exploring socio-ethical dilemmas using scientific and technological metaphors: SF's power for critique also been noted by Haraway [6] and has been used to create academic syllabi such as Speculating Futures[1]. The stories we adopt in the course explicitly feature critiques to innovation, progress, or specific pieces of technology, since they provide the key benefit of being easy to connected to contemporary technological controversies, such as privacy and AI, and their ease in creating grounds to generate scenarios for debates [9].

In the course, we assign student teams a short story three weeks before their Battle. The ensuing Battle preparation meeting starts by discussing the short story, and then proceeds by co-creating the scenario. With this adaptation, scenario building can now see a more active contribution of the students because, through the short story, they can better grasp the scenario's pedagogical intent. As an example, students can give feedback and help the process of generating the debate positions based on the tensions they found in the short story. The meeting then finishes as per our normal model, with teams being assigned to one of the two positions.

4 CONCLUSIONS/FUTURE WORK

In this contribution, we presented an evolution of Tech Battles which adds a second preparatory activity: the reading of a science fiction short story connected to the Battle's theme. We think the short stories may help making Battles more scaffolded and replicable in other contexts though, as of the time of writing, we have not explored the deeper implications of the introduction of this extra step, and neither have we obtained empirical validation.

The immediate next step of this work will revisit the Battles' design and include the reading of the short story. We will also need to gather how the students' perceptions changed, exploring how short stories influence the students' understanding, their preparation for the debate, and the development of non-technical skills. Since many years, we always gathered students' feedback connected to Battles, which by now forms a small source of longitudinal data. This intervention, however, is likely to require an *ad-hoc* validation of the change, defining some new indicators for gauging its effects.

Another line of inquiry is connected to the selection of the short stories: should they remain the same across the years, or should they change? In this edition of the course, we pre-selected short stories from our own reading experience. If stories could change over the years, though, should we create a systematic selection procedure, for example using stories from collections that won literary prizes? Another alternative could be instead to base our selection on literature discussing reading science fiction as a curricular activity. Could we, for example, imagine a partnership between our I&E Basics course and courses such as Speculating Futures, where the latter proposes short stories and commentary, and the former uses them for debating? And, if so, how could we contribute back?

[1] See http://speculatingfutures.club/ or https://github.com/frnsys/speculating_futures (both URLs accessed 2023/10/11).

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Appendix B

Paper B

Revisiting Tech Battles Using Science Fiction: Methodological Implications and First Impressions

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***Abstract*—The development of non-technical skills, such as critical thinking and public speaking, is increasingly recognized in computing curricula as essential for computing professionals in the job market. Universities are adopting active learning methods to cultivate these skills, among which are debate-based teaching methods. Previous literature showed that debating is used in many knowledge domains, and can help develop skills of information synthesis, critical thinking, and effective verbal communication. In spite of these benefits, however, debating in computing education is still rare. This work explores a partial redesign of a debates-based teaching method, called Tech Battles, implemented in a 6-ECTS non-technical course at the University of Trento targeted to first-year Master's students in Computer Science with a minor in innovation and entrepreneurship. Battles have been part of the course since 2013, and over the years the teaching team upgraded the methodology, which now foresees a preparatory activity where students read a science fiction short story assigned by the teachers. In this paper, we discuss how this latest modification changes the course and its impacts: how the workflow of each debate evolved, our criteria for selecting short stories, preliminary observations gathered from the field, and the research methods that will be used to more thoroughly validate the updated method.**

***Index Terms*—debates, computing education, active learning**

I. Introduction

The highest academic aggregators in computing (the ACM and IEEE) acknowledge the growing importance of developing non-technical skills in computing curricula, including critical thinking and public speaking [1]. Such skills form an important part of what is expected of computing professionals in the industry, and are frequently developed — though implicitly — in computing curricula through courses in Innovation and Entrepreneurship (I&E) [2], [3].

The last decades have also seen an increased emphasis on active learning, of which a specific case is debates-based teaching. While debates are used across various knowledge domains [4] to foster skills such as information synthesis, critical thinking, and effective verbal communication [5], their integration into computing education is still rare.

Since 2013, our teaching team adopted a debates-based teaching method, called Tech Battles (Battles), in a curricular and mandatory Master's course for computing students at the University of Trento. The course and its methodology follow a practice of continuous improvement and innovation, where we continually assess how to adapt our teaching to a constantly-changing world. Recently, we focused our attention to two frequent issues in our use of Battles: (1) ensuring students understand the grounding of each Battle, and (2) enabling teachers to generate good Battle topics and scenarios.

This paper expands our recent work at SIGCSE 2024 [6], and more in general our previous work at TALE 2020 [7]. In this article, we present *ex novo* the redesigned Tech Battles teaching method, and give our first impressions of how our updates are changing the course.

We start in Section II with a brief overview of the state of the art in debates-based teaching and science fiction in computing education; Section III describes the context where our intervention takes place; Section IV details our methodological upgrades and a workflow example; Section V presents some preliminary results and discussions based on our field observations, and Section VI outlines our plans for future work and broader reflections.

II. State of the art

As computing is a rapidly-evolving field, its teaching methods also face the need to adapt to remain up to date. While traditionally computing curricula focused on technical knowledge [1], recent shifts have emphasized competencies and attitudes [1], resulting in an increased interest on soft skills. These skills are challenging to cultivate through traditional learning methods [5], leading to a rise in the adoption of active learning approaches. Debates represent a particularly interesting case within active learning: debates are frequently adopted in humanities and law, and have been presented as a solid way to prepare students to defend their ideas in both industry and research settings [8]. Despite potential benefits in skill development, such as improving argumentation, interaction between students, and teaching students to construct well-grounded arguments [8], [9], their use in STEM subjects remains limited [8].

The effectiveness of debates, however, critically hinges on the selection of appropriate topics. A well-chosen topic should stimulate students' thinking and deepen their knowledge [9] but also present clear opposing sides, and facilitate students in comprehending distinct positions and considering different perspectives [10]. The topic selection also strongly influences student engagement, and an inappropriately-chosen topic may lead to a loss of student motivation [11].

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More recently, debates have been used in computing within technology ethics courses, with some teachers basing in-class discussions on science fiction stories to offer a distinctive starting point for discussions surrounding ethical dilemmas within the realms of technology and computing [12], [13]. Crucially, work by Vrasidas et al. [14] showed that science fiction stories help students forming relevant emotional links that aid them in understanding learning activities, and that science fiction may aid the students' critical reflection in establishing connections between literature and technological development. The same article also argued that these narratives enable students to develop research, debating and decision-making skills, which are helpful both in everyday life and in addressing science-related social and environmental problems.

Within the computing education domain, the use of science fiction has been argued to enhance — similarly to debates — student engagement, critical thinking, and creativity [15], though its use still remains niche [16], [17]. Initiatives like MIT Technology Review's "Twelve Tomorrows" and Intel's "The Tomorrow Project", however, indicate a growing interest in leveraging science fiction as an educational tool to envision technology's societal integration [12].

This evolving landscape which sees both debates and science fiction as underexplored but powerful educational tools in computing education serves as the background in which we position our intervention, which aims at offering students a comprehensive view of technological innovations and their societal implications.

III. Pedagogical context

Our intervention takes place in a 6-ECTS non-technical course at the University of Trento and explores a debates-based teaching method described in our previous paper [7]. The course which includes our method is targeted to first-year Master's students in Computer Science (CS) following a curriculum which combines CS with innovation and entrepreneurship. The content of the course teaches elements of socio-economic impacts of computing and innovation, while developing soft skills (know-how) [1] such as oral communication, clear presentation and critical thinking.

The course has been running since 2013, with greatly varying class sizes but, since the last four editions, it has stabilised to having around 40 attending students per year. In the course, students are divided in teams of 4-5, and pairs of teams debate opposing view on a current trend in digital innovation. Each debate, called a Battle, takes place within a scenario, a hypothetical plausible world that combines real-world and fictional elements set around a key central tension. Each Battle is structured in 3 phases:

- a 1-hour preparation meeting, done outside class time, two weeks before the Battle. The two teams and the teachers create the scenario and define what points the teams should debate about;
- the Battle itself, done in a two-hour class slot, where the two teams engage with each other, and the rest of the class takes the role of an active audience, asking questions and ultimately voting for the more plausible proposal;
- a report, delivered at the end of the course, in which the two teams synthesize the knowledge acquired through the process and reconcile their positions.

A. Problem and gap

In our current teaching method, the preparation meeting poses challenges for both students and teachers. From the students' perspective, this meeting serves as their initial exposure to the Battle's topic and scenario. Our previous observations indicated that students found it demanding to quickly comprehend the direction of the Battle while simultaneously navigating the scenario. Teachers, similarly, face the crucial challenge of creating the fictional wrapping that forms each scenario. This imaginative task is repeated for each Battle in a course, and teachers need to consistently tap into their creativity. While this has not been a problem for us so far, we recognise that creativity might be an individual competence, and simplifying the teachers' task could enhance the method's replicability.

In this work, we propose a partial redesign of our teaching method, which introduces an activity before each preparation meeting where students read a science fiction short story assigned by the teachers. We explore here the implications of this update, including changes in the workflow, our criteria for selecting short stories, preliminary field observations, and planned research methods to get more solid validation for the updated approach.

IV. Re-design proposal

The Tech Battles teaching method is in constant evolution but, over the last few years, we have made some fundamental changes, which we will now illustrate by discussing in detail our approach's four phases.

A. Preparatory reading

Our first step, responding to a past struggle on the side of the students of the debate's context, is the reading of a science fiction short story. As discussed in Sec. II, suitable stories can help students develop a critical view of technology, broaden their imagination, and introduce key themes and opposing viewpoints for their Battle. These narratives serve as a starting point for teachers to create scenarios, framing Battles as genuine controversies and streamlining the process of scenario generation.

We chose science fiction due to its ability to explore ethical and societal dilemmas through scientific and technological metaphors, and short stories in particular to better meet the time limitations of the course and to ensure an easy comprehension in a short span of time. The teachers' crucial task is that of selecting appropriate stories that can foster critical perspectives on innovation, progress, and technological advancements, sparking thought-provoking discussions on timely technological debates like privacy and AI. The criteria for selecting readings included: (1) the existence of a technology

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Fig. 1. The general workflow of each Battle, that each pair of teams of students follow.

or technological problem that creates controversies linked to a socio-ethical concern; (2) a fair, critical perspective concerning the technology; (3) conciseness, allowing students to complete the reading within roughly one hour; (4) an overall topic that has clear connection to mainstream technological debates.

Students, which are grouped in teams and assigned to a debate in the first lessons, receive their reading three weeks before their Battle. They are then given one week to read and understand their story, and reflect on the story's main themes.

B. Battle Preparation

Two weeks before each debate, students and teachers participate in the Battle Preparation, a one-hour meeting where the participants collectively decide the goals and boundaries of the upcoming Battle in a spirit of joint creation. Our earlier designs [7] included the participation of two extra students with a coach role, which remained constant for the whole course, and that we have since removed.

The meeting starts with the teacher asking the students to give a concise summary of the reading, emphasizing key points in the narrative, to establish a shared understanding among the participants. A key step during this phase is to ensure that everyone shares an understanding of the ethical and societal contradictions that appear in the story to lay the foundation for discussion. Once this alignment is reached, the teachers propose a scenario based on the short story's controversy, and defines short labels that define the two positions that will face each other in the debate.

After the two positions are defined, teachers and students collaborate to improve the scenario if needed, and create a clear list of elements that each team must incorporate into their "opening statements" presentations. Defining these elements establishes a common ground for the Battle, ensuring that the two opening statements align with the central tension, and that the two teams have opposing views on the same sub-themes.

At the end of the Battle Preparation, the teams decide which of the two opposite positions they want to take or, if they are undecided, they are randomly assigned to a position.

C. Battle

Each Battle starts with the teacher providing a brief introduction of the scenario, providing some fundamental context to the audience, helping them to become active participants.

The core phases of the Battle, which are unchanged from our previous design, consist of "opening statements" presentation from each team, two rounds of open debating, and "closing statements". The final part of the Battle, however, is quite different. As a minor change from our previous model, both teams are now evaluated equally (unless one team was radically better prepared than the other), aiding the students in seeing each Battle as the collaborative building of a performance rather than a win-lose situation. Most importantly, however, we now include in each class a reflective phase, divided between "course corrections" and "technical suggestions".

As we stated in our previous contributions, the teaching team has to keep the role of an impartial moderator. This impartiality is fundamental to create a fair debating (and learning) environment, but it has in the past prevented teachers from calling out content mistakes made by students in the name of balance. During "course correction", teachers point out content mistakes that were made during the presentation and provide short points of feedback connected to each presentation's content. During the "technical suggestions", conversely, teachers focus on giving practical suggestions on language, delivery, and presentation design to help students improve their work. This adjustment enables the teaching team to effectively fulfill their roles as both moderators and content holders.

D. Battle Report

The final phase, the "Battle Report", is unchanged from our previous work: after the end of the course, the two teams jointly write a short report synthesizing the insights gained during the Battle and reconciliating the two opposing positions.

E. Battle workflow example

As an example of our updated model, we briefly present here the full flow of a Battle, from reading to report:

1) Reading: Three weeks before their Battle, students received a reading: "The Truth of Fact, The Truth of Feeling" by Ted Chiang [18]. In the short story's two sub-plots, the main characters deal with issues of trust and truthfulness, driven by the introduction of technologies that reshape their definitions of privacy and transparency.

2) Scenario: We created a scenario where the ocular camera featured in one of the story's sub-plots (and its annexed publicly-searchable audio/video archive) is a reality. The request for the teams of students will be to develop alternate value propositions, and different world views, based on the same technology: one where every video captured by the

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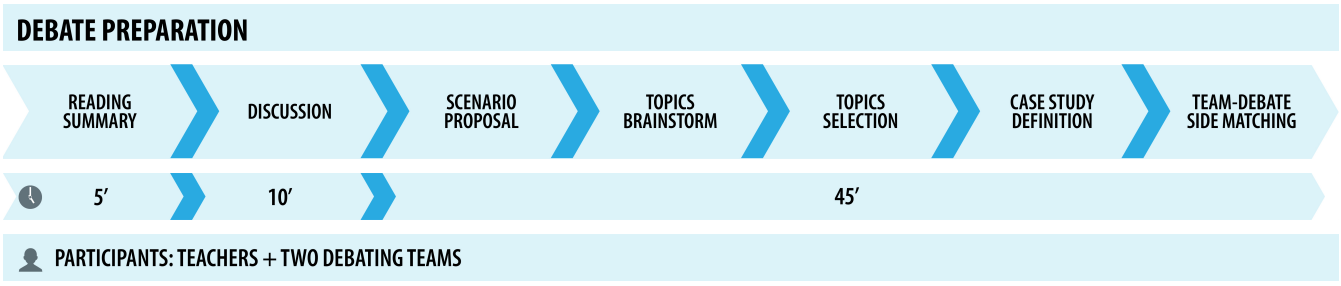


Fig. 2. The structure and sub-phases of the Battle Preparation meeting.

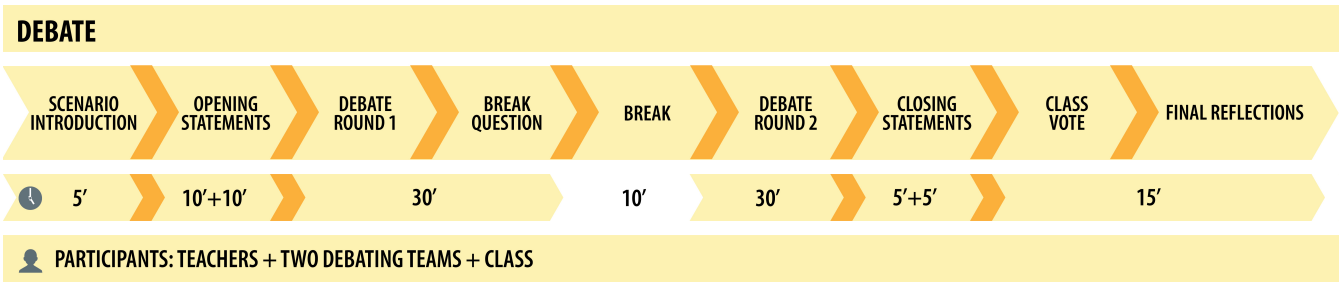


Fig. 3. The structure and subphases of the Battle itself.

camera is openly accessible to everyone (the "transparency world"), and one where individuals have complete control over their videos they record (the "privacy world").

3) Battle preparation: The teams and teachers summarised the story, then reflected together on the two views, ultimately agreeing on four main points that the opening statements presentations should contain: (1) how each world broadly looks like; (2) how their world deals with crime; (3) how journalists operate in their world; (4) their world's "killer app" — justifying why most people decided to adopt the ocular camera. The preparation meeting closed with each team being assigned to one side.

4) Battle: The two teams presented their positions: the "privacy world" focused on data protection and authentication, empowering individuals to choose who gets access to data, and leveraging this to safeguard whistleblowers; the "transparency world" proposed a world where incentives for crime are drastically reduced and greater research/industrial collaboration, with competitions limited to challenges of skill rather than information asymmetry.

5) Report: The two teams reconciliated their views in their Battle Report, ultimately proposing a third view that takes into account what happened in the Battle, providing their reconciliating "fair tale" [19].

V. Preliminary Results and Future Works

In A.Y. 2023/24, the first iteration of the redesigned course, we had 31 attending students and formed 8 groups for 4 Battles. As bases for the debates, we selected three science fiction short stories from "Exhalation" by Ted Chiang [18]: "The Lifecycle of Software Objects", which led to discussions about the implications of virtual life; "Dacey's Patent Automatic Nanny", which was the basis for a Battle on the potential use and effects of Artificial Intelligence in digitised education; and "The Truth of Fact, the Truth of Feeling", as also outlined above, prompted students to debate the controversy surrounding privacy and transparency, versus transparent personal data. The fourth debate was based on "The Ones Who Walk Away from Omelas" from "The Unreal and the Real" by Ursula Le Guin [20], where discussion revolved about uneven benefits of technological development.

From our anecdotal experience and preliminary looks at the students' end-of-course self-reflections, we have observed a generally high understanding of their debates. In the past, students faced challenges in understanding the overarching topic of their Battle and its connection to the scenario. The use of the short stories to construct scenarios has facilitated a deeper understanding among students. This addition helped enhancing the learning experience, but also addresses conceptual gaps that students may encounter with complex topics and scenarios.

Even in our limited experience, not all Battles were successful. One, in particular, had to be rescheduled: while students had clearly understood the central tension of their Battle, the two teams had different understandings of what they needed to include in their opening statements, leading to too little common ground for a fruitful debate. This unsuccessful Battle highlights that, while we see an improvement in our methodology, it still is not trivial to understand for students, who can face difficulties in creating presentations for a solid debate.

Language barriers posed another challenge for students. The course is taught in English, and in this particular year uneven

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language proficiency often made students find themselves struggling to articulate their arguments effectively.

An undoubtedly positive note has been that this year we observed more interactive Battles, highly involving the teams and the audience. In our previous iteration, the students themselves explained the scenario to the class, while the teacher now introduces the scenario, resulting in an audience with a clearer understanding — which is ultimately more engaged and active, posing numerous questions and providing a stimulating environment for the debate.

The introduction of the final reflections has also been a positive addition. As Battles passes, teachers made fewer and fewer observations, particularly regarding technical suggestions, as students integrated the corrections provided in previous debates.

VI. Conclusions

In this contribution, we detailed our updates to the Tech Battles teaching method, notably with the addition of a preparatory reading of a science fiction short story, and outlined preliminary reflections on the redesign.

We already observed potential limitations of our approach when teams faced challenges in following a tighter presentation outline. This aspect will be closely monitored in future iterations, acknowledging our currently small sample size.

We also observed several promising trends. The short stories greatly helped in focusing preparation meetings, making it easier to introduce the central tension of each Battle. By selecting short stories covering themes that are connected to current events, students quickly grasped the relevance of the story and the debate in general. The "course correction", finally, cemented each Battle as a learning opportunity for the whole class, consolidating the teaching team as both moderators and content facilitators.

The short stories also aided new members of our teaching team in grasping the general Battles methodology and scenario creation. Further investigation should go towards making Battles even more replicable outside our context, potentially through the creation of implementation guidebooks. Ongoing work includes a comprehensive mixed-method analysis of anonymous student surveys, comparing results to previous implementations when relevant.

In closing, we propose a reflection about the intersection of science fiction with computing education. Research in Futures Studies recently argued that we are crossing times of "imagination crisis", where we individually and collectively struggle to imagine positive futures [21]. As mentioned in Section II, the science fiction read by engineering students are sometimes linked with what technologies those engineers will create [15]. If technologies are socially constructed objects, and we wish to orient technology for planetary good, we ought to reflect more deeply on where technology is first envisioned. Computing educators have the opportunity to claim a stronger role in shaping the future technologists' imaginations, and in guiding them to see technology creation as a responsible act.

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Appendix C

Paper C

Choose Your Own Adventure: empowering students to combine structured and open Challenge-Based Learning

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***Abstract*—Challenge-Based Learning (CBL) is being increasingly adopted in engineering education, including in mandatory courses. Recently, authors have described a tension between structured and open approaches to CBL, with significant pedagogical trade-offs in both cases. This Work-In-Progress Innovative Practice article proposes "Choose Your Own Adventure in Challenge-Based Learning" (CYOA-CBL), a model which reconfigures the open/structured CBL duality as a spectrum, and empowers students to fine-tune their learning by making their course more structured or open. Through CYOA-CBL, we hope to give our contribution to making CBL more replicable and better aligned with diverse student motivations.**

***Index Terms*—Challenge-Based Learning, innovation and entrepreneurship, student choice**

I. Introduction

At FIE 2022 Bombaerts, Martin, and Doulougeri described three courses that used Challenge-Based Learning (CBL) to teach ethics to engineers, and loosely defined *structured* and *open* CBL in the process [3].

In the article, Bombaerts and colleagues define structured CBL as a context where "[the] university [defines] what the important aspects are that have to be learned", and open CBL as one where "students [decide] for themselves how much or how little [content the course] should entail". The authors also discuss some trade-offs that ensue from both approaches: structured approaches are easier to assess, more comfortable, and favour depth; open approaches are more demanding, better reflect the wicked nature of challenges, and are more creative.

This distinction has been relevant in reflecting on one of our own CBL courses, a second-year Master's course for Computer Science students, acting as the final course in a "minor in Innovation and Entrepreneurship" (I&E). The course, that first ran in 2017, is taken every year by 45 to 70 students, and involves 4 to 7 external stakeholders as challenge providers. The course is mandatory, and many of the involved students are part of a double degree programme called *EIT Digital Master School*[1]. The heterogeneity of the students is reflected in widely different levels of intrinsic motivation [2], knowledge, commitment, willingness to engage, and preference for a course that is either more structured or more open.

In this article, we want to sketch our Work-In-Progress proposal to create a single teaching context that can flexibly cater to students with different wishes. Authors in the literature called CBL as more demanding for students and teachers [7]: by re-positioning the structured/open trade-off from a problem of course design to a student choice, teachers can match more easily their work to the students' motivation and, we believe, can contribute address some of CBL's scaling woes.

We call our proposal "Choose Your Own Adventure in Challenge-Based Learning" (CYOA-CBL). CYOA-CBL structures the course in a sequence of "phases", and defines alternative "paths" that can be taken by the students. Students have several alternatives to tackled each phase, representing alternative ways to explore solutions to challenges, and may opt to follow a pre-defined path (a structured approach), create their own path and leverage their own knowledge (an open approach), or adopt an in-between solution.

CYOA-CBL represents, to the best of our knowledge, a novel approach, and gives two main contributions to the area of CBL in engineering education: first, it proposes to re-define Bombaerts' structured/open trade-off as a spectrum rather than as a duality; second, it aims to start a deeper reflection in how to address the matter of CBL's scalability by giving CBL courses a replicable yet flexible structure.

This article will proceed in the following way: section II will give some additional background information about CBL and why CYOA-CBL might be useful; section III will go more in depth on our proposal, explaining the CYOA structure, as well as giving an example of a complete path, and of alternative approaches to an individual phase; section IV, finally, will provide some points of reflection and avenues for future work.

II. State of the art

In the seminal paper that described CBL, Nichols et al. [11] called traditional teaching "increasingly ineffective". Part of

[1] https://masterschool.eitdigital.eu/

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this ineffectiveness is due to the enormous amount of information available on the Web, including Open Educational Resources (OER), shifting the goal of teaching and learning from obtaining knowledge to critically assessing it [15].

Consequently, the last decades have seen the rising popularity of active learning pedagogies, and in particular the class of *X*-Based Learning pedagogies such as Team-Based Learning, Project-Based Learning, Problem-Based Learning and, most recently, Challenge-Based Learning. As discussed by [18], these methods have many common features, and CBL can be seen as one of the most complex ones: in CBL, students are engaged in a "challenge" provided by an external stakeholder, and they can decide the shade of the challenge, and be more independent in choosing their own goals [10], [19].

CBL is most frequently used in engineering education [8], as it develops important skills for the development of new engineers in a rapidly changing world, including work in multidisciplinary teams, communication, conflict resolution, collaboration, management of resources, entrepreneurship, critical thinking and problem-solving (again, [8], [18]). As such, CBL can be a good fit to teach non-technical courses in computing curricula, such as those involving innovation skills [4]. However, as [8] also notes, CBL research is still limited and not well established, meaning that many institutions still face substantial trouble in deploying CBL.

CBL courses are frequently the cause of student frustration, especially at the courses' beginning. Doulougeri et al. [6] identified six frequent difficulties that students encounter with CBL: 1) establishing an understanding of the course expectations 2) narrowing down the broad challenge and setting clear goals 3) applying content knowledge to the challenge 4) diving the tasks among group members 5) managing the time 6) managing group processes. In a mandatory CBL course like our own, these difficulties may be further exacerbated.

Our proposal in this article wishes to propose a new CBL structure that helps give some scalability to CBL — not much in terms of teacher-to-student ratios, but rather in creating a process which is replicable, more manageable, and adaptable to varying student motivations.

III. Our proposal

As mentioned above, students taking mandatory courses may have highly diverse motivations [2]. Consequently, the scaling of CBL, which is frequently applied to extra-curricular activities, to curricular courses cannot be fully painless: as noted by [13], CBL courses are more demanding for all involved stakeholders, including staff and, most importantly, students. Many university students are already subject to stress in university settings [5]: if more courses were to adopt CBL — and thus become more demanding as per [7] — students' stress levels may increase even further.

In some ways, this tension is already present in the "structured" and "open" CBL duality: if students have highly diverse motivations, it is likely that, independently from whether teachers take a structured or open approach, their choice will be at odds with some students' motivations.

To solve this tension, we propose to look at the categories of "structured" and "open" CBL not as a dichotomy, but as two ends of a spectrum, and let students position themselves on this spectrum. This is the essence of CYOA-CBL: empowering students to adapt a CBL course to fit their motivations.

Our name, "Choose Your Own Adventure", is inspired by a series of books where readers go through a story featuring several decision points. Readers may, for example, decide if the character in the book should take the left or right path at a crossroads; the story would then evolve accordingly, with each reader experiencing a variant of a general cohesive story. Similarly, a CYOA-CBL course aims to be a cohesive experience, while letting students choose alternative paths.

A. General structure of CYOA

As with any other CBL course, CYOA-CBL foresees students divided into teams facing a challenge proposed by an external stakeholder.

Previous authors have underlined the importance of dividing the CBL process in phases to help students make sense of the process [1]. In CYOA-CBL, we foresee six phases, loosely mapped to the popular "engage/investigate/act" cycle [12]:

- **challenge identification**, where students explore the challenge proposed by the provider and delimit its scope;
- **problem space exploration and goal-setting**, where students analyse the challenge, gather information and agree on a general idea that they wish to pursue;
- **work plan definition**, where the team splits work internally, defines internal deadlines and plans the project;
- **investigation**, where students gather data to support the validity of their idea as desk research or as field work;
- **analysis**, where the team analyses the data obtained from the previous phase;
- **solution proposal(s)**, where students finalise their work into one or more possible solutions for the challenge.

For each phase, teachers prepare several packages of teaching materials (e.g. videos, tutorials, readings, etc.) and exercises, representing alternative ways to enable a form of just-in-time learning that helps students reach the goals of that specific phase. Each phase also has a common *worksheet*, a checklist that doubles as a way for students to check that they have fulfilled all the requirements for that phase and as assessment.

The specific teaching materials and exercises are different for each CYOA-CBL course, and are based on each course's angle (e.g., a course featuring many business challenges may prioritise business content; one with social challenges may prioritise social content). Open Educational Resources can help teachers create these packages efficiently, so that they can focus on mentoring the students. Worksheets, instead, are common for all courses using a CYOA structure, containing guiding questions, and checklist elements such as "have you completed the suggested exercise for this phase?".

The sequence of the six pairings between phases and specific content/exercises students used in each phase is called a "path". When implementing each CYOA-CBL course, the teacher curates some predefined paths, with activities proposed

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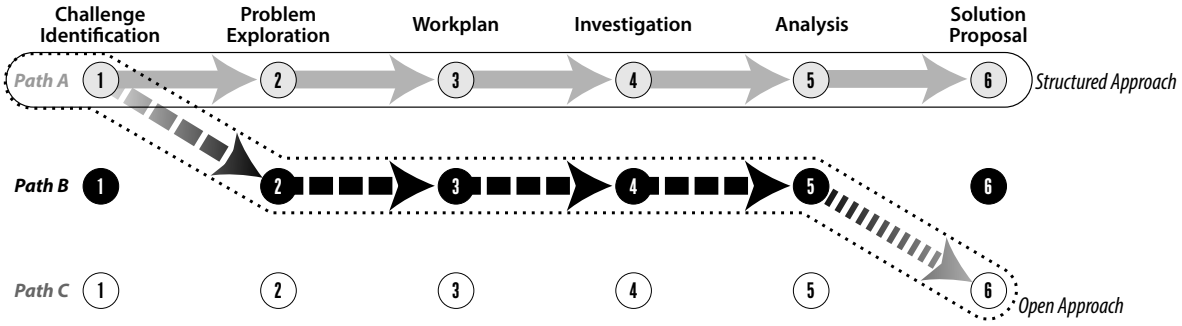


Fig. 1. The phases-and-paths structure of a CYOA-CBL course, with two possible approaches for going through the course.

for each phase. In Figure 1 we give an example of a course, with three predefined paths, generically called "Path A", "Path B" and "Path C". These predefined paths give the students' work a specific flavour, such as a "business modelling" path or a "product development" path. Teams of students may freely switch between paths, or propose their own approaches to the various phases.

This flexibility gives students the possibility of having a more structured or open experience, with three options:

1) follow a predefined path proposed by the teacher;
2) switch between different predefined paths on a phase-by-phase basis;
3) propose their own activities for some (or all) phases.

These three options create a spectrum that goes from fully structured CBL to a much more open experience. Again in Figure 1, we give an example of a team of students choosing a structured approach (linearly following Path A), and a more open approach (switching from Path A, to B, and then C).

We will now present in more detail a whole predefined path and some alternative options that may be used in a phase.

B. Worked example: the Scenario Modelling path

Many challenges in the course we designed CYOA-CBL for come from startups or early-stage business ideas, and often require exploring potential directions for the providers.

We propose here a possible "Scenario Modelling" path, whose goal is to examine a range of potential futures for the challenge provider, and outline plausible solutions. For this path, the teacher provides the students with these activities for each phase, summarised also in Figure 2:

- **Challenge Identification**: students perform a mission definition activity, for example using the Business Model Canvas [14]. Through this exercise, students get a better understanding of the provider's context, and identify potential areas of intervention.
- **Problem Space Exploration and Goal-Setting**: during this phase, students investigate external factors that influence organisations such as the provider. Through the "11 Sources of Disruption" exercise[2] students explore what is the state of the art and new innovations in the provider's industry, and determine the essential aspects that impact the challenge. To close this stage, students create a loose list of potential scenarios they want to explore.
- **Work Plan Definition**: in this phase, students decide more precisely the direction their work will take, creating a plan to manage their project. Teachers may run, here, a workshop on how to divide responsibilities and workloads, using simplified Gantt charts to develop a roadmap with goals and milestones.
- **Investigation**: students work on scenario creation, using for example the "Three Horizons Framework" [17], and find evidence to support these scenarios through research on online databases such as Statista[3] or the United Nations Open Data website[4], or perform field work using Strategic Interviews [16].
- **Analysis**: to validate proposed scenarios, students use exercises such as the First Mover Advantage [9] to analyse their work critically. The phase also includes a short reflection step where students check whether the scenarios they developed fit with the goals and constraints identified by the students in the previous phases.
- **Solution Proposal**: in the last phase, students use frameworks such as the Preferred Future Canvas[5] to argue what the most likely scenario could be, and produce a deliverable that will be assessed by the course' teachers. The final deliverable can be a written document, but also a presentation, or other forms such as an infographics [6].

C. Worked example: alternatives for the investigation phase

The second example further explore the Investigation phase, and proposes possible alternatives for its completion, which we also present in Figure 3.

To complete the investigation phase, teams may:

- work on scenario creation using the Three Horizons framework, in a scenario modelling path;

[2]https://sloanreview.mit.edu/article/the-11-sources-of-disruption-every-company-must-monitor/

[3]https://www.statista.com

[4]https://data.un.org

[5]https://futuresframework.com/preferred-future-canvas/

[6]https://docs.google.com/document/d/1MikaQXHhXvmOmUU1kPwcLW6Ofrod6qBIII6ZmOyxJ2c

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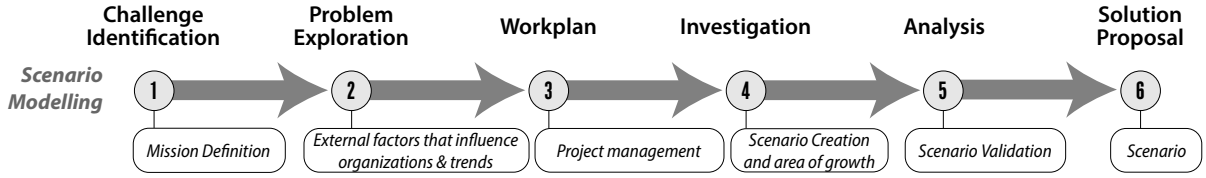


Fig. 2. A "Scenario Modelling" path, with potential exercises defined for each of the six phases.

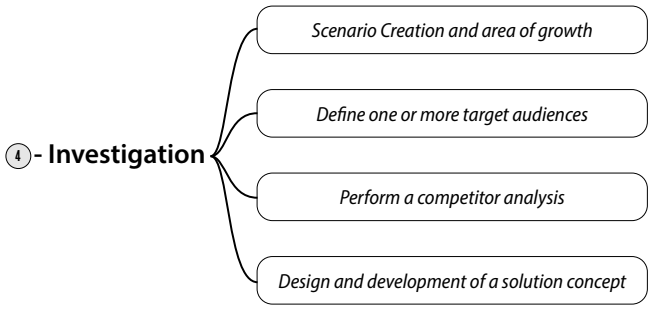


Fig. 3. Potential alternative approaches to the investigation phase.

- define one or more target audiences using the buyer-persona template[7] and interview the selected segments, if they're following a customer-product fit path;
- perform a competitor analysis using the Volatility, Uncertainty, Complexity & Ambiguity framework[8], if they're following a market analysis path;
- design a solution concept through The Open Group Architecture framework[9], as an open path.

IV. Discussion & conclusions

The WIP nature of CYOA-CBL means it still needs to be rigorously tested in the field. For our next steps, we plan to explore real-world examples with detailed lesson plans, as well as analyse data gathered during the tests to get evidence for CYOA-CBL's effectiveness.

The first application of CYOA-CBL took place during a two-week summer school. We tested CYOA-CBL on a small scale, with highly motivated students. We gathered qualitative data during and after the summer school through surveys, field observations, and teacher interviews which, as of the time of writing, are not yet ready for publication. We foresee using a similar methodology for testing CYOA-CBL in the capstone innovation and entrepreneurship course described in the introduction. Most relevantly, this course is curricular and mandatory, forcing us to reckon with a wide range of intrinsic motivation on the students' side.

CYOA-CBL also has some limitations on the teaching side. The most critical, we believe, lies in the significant setup effort. In our previous experiences with CBL, teachers needed little preparation to run classes or mentoring sessions, relying instead on their extensive experience to adapt to the students' needs. With CYOA-CBL, teachers will need to devote significant effort in setting up the course's structure, preparing worksheets, and designing paths.

Ultimately, CYOA-CBL is about improving CBL's long-term viability and scalability. The extensive experience of our teaching team can not be taken for granted, and indeed many of the teachers that historically worked on our course will eventually need to step down. If a teaching team has limited access to experienced and flexible mentors, CYOA-CBL may be a viable strategy to build teaching capacity by relying on a well-designed overarching scaffold. The paths-and-phases structure of CYOA-CBL, with its worksheets and exercise/reference libraries may aid teachers in focusing their improvisation and creativity skills on students that wish to take open approaches, while providing high-quality exercises for students who prefer or need a structured approach.

Most importantly, and perhaps most innovatively, we see CYOA-CBL as an act of student empowerment: CBL inevitably adds complexity to the teaching context, and some design choices that teachers may take in positioning their course as a structured or open approach may not fit with the students' needs. CYOA-CBL returns the decision of how much engagement and creativity students should invest in a course to the students themselves, giving them autonomy in their positioning in the structured-open spectrum.

In this Work-In-Progress paper, we outlined our design for a possible pedagogical method that, not without significant setup effort, overcomes the existing duality between structured and open CBL approaches, allowing students and teachers to adapt a course to follow their needs. Our hope is that these reflections can serve as a conversation starter in the community that applies CBL to engineering education to more thoroughly discuss CBL's alignment with students' and teachers' motivation and, ultimately, its pedagogical sustainability.

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[7]https://miro.com/templates/buyer-persona/
[8]https://www.vuca-world.org
[9]https://www.opengroup.org/togaf

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Appendix D

Paper D

Enabling Computer Science Students to Choose Their Own Adventure in a Mandatory and Curricular Challenge-Based Learning Course

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***Abstract*—This research-to-practice full paper describes the results we got from enabling students to fine-tune their own learning experience in a Challenge-Based Learning (CBL) course. Engineering educators have been working for several years on how best to integrate CBL into computing courses, recognizing CBL's role in fostering crucial skills such as critical thinking and problem-solving. At FIE 2023, we proposed a possible scaffold named "Choose Your Own Adventure in Challenge-Based Learning" (*CYOA*-CBL) that aimed to make CBL more adaptable and empower the students to personalise their experience, positioning themselves in a spectrum ranging from a more open and creative approach to a more structured and guided CBL experience. During the past academic year, we implemented *CYOA*-CBL in a mandatory four-month course at a medium-sized European university. With this work, we present the results we got from a qualitative study where we used mixed methods of data collection to evaluate *CYOA*-CBL and verify whether students understood the course process. In this paper, we discuss how students tended to adopt both open and structured approach and they appreciated the flexible nature of the course, leveraging the opportunity to change their path during the process to adapt it to their challenges. Students also valued the recurring structure of *CYOA*-CBL mentoring and tutorials and they had a general good understanding of the "next steps" to perform. At the same time, they highlighted the need to improve the tutorials, even if in a controversial way.**

***Index Terms*—Challenge-Based Learning, innovation and entrepreneurship, active learning, computing education, mixed methods**

I. Introduction

Challenge-based learning (CBL) has gained popularity in recent years, particularly in the STEM fields and computing [1]. This rise in popularity can be attributed to the skills that CBL has been suggested to develop in students [2]. Indeed, CBL stimulates in students skills such as critical thinking, problem-solving, and teamwork, qualities that are now highly requested [3].

CBL, however, is still in an emerging phase and therefore is not yet an established practice. Some aspects of CBL, such as guidelines on how it should be implemented, still need to be developed [4], and further research is needed to establish new approaches to make CBL more adaptable to various learning contexts. As well explained by Perna et al. [5], one of the current challenges for CBL is to tackle the barriers that prevent its implementation in higher education institutions. There is indeed a need to make this methodology more widely available, and develop an approach to CBL that accommodates various needs, ranging from the variable number of students, courses being compulsory or not, level of student motivation, teacher expertise, available resources, and more.

During FIE 2023, we presented a scaffold named "Choose Your Own Adventure in Challenge-Based Learning" (*CYOA*-CBL) that aim to make CBL more adaptable to a broader range of contexts, such as those described above, by empowering students to self-tune their own learning path.

CYOA-CBL divides a CBL course in six phases and for each phase, teachers prepare several packages of teaching materials and exercises. The sequence of the six pairings between phases and specific content students used in each phase is called a "path". Students can follow a predefined path proposed by the teacher and have a more structured experience or switch between different paths on a phase-by-phase basis and have a more open experience.

In fall 2023, we decided to adopt and test *CYOA*-CBL in one of our curricular and mandatory courses: with this work, we want to present some reflections on the implementation of this new approach based on data gathered from surveys and interviews. By sharing our experiences, insights, and points of improvement, we seek to contribute to the ongoing research on CBL in computing education, going towards making CBL deployable in a greater variety of learning environments.

This article will proceed in the following way: Section II

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will open by outlining *CYOA*-CBL's theoretical basis, positioning it in the literature and discussing its implications for the practice of computing education; Section III will go more in depth on our proposal, describing the pedagogical context where we implemented *CYOA*-CBL; Section IV will present the methods used and the sampling of this study; Section V will presents and discusses the data gathered; lastly, Section VI will provide some points of reflection on our successes, failures, potential improvements and future work.

II. Background

In computing education, teachers are adapting to fast-sweeping digital transformation by exploring new teaching methods. The widespread availability of information and the ease of accessing it, have led to the question of whether traditional teaching methods are still adequate or if it is necessary to adapt them to the new era [6]. Some authors now consider traditional teaching to be ineffective [1], viewing education not merely as "acquiring knowledge" but more as "critically evaluating knowledge", which aligns with the perspectives in [6].

For this reason, in recent years, new teaching methodologies have gained popularity, particularly the so-called active learning approaches. A particular case is that of methods such as Project-Based Learning (PjBL), Problem-Based Learning (PbBL), Team-Based Learning (TBL), Case-Based Learning (CsBL), and Challenge-Based Learning (CBL), which have been grouped as a single family of methods called X-Based Learning (XBL) [7]. These methodologies have been proven to foster essential skills in students, such as collaboration and creative thinking, which align with the competencies sought by employers today [8], [9]. They also align with the requirements of computing curricula, which typically focus on student employability and post-university life [10].

As discussed by Sukacke et al. [2], while XBL approaches share many common features, CBL seems to be the most advanced and an evolution of the previous ones. Nichols and Cator proposed the initial definition of CBL, describing it as "a [...] multidisciplinary approach [...] that encourages students to [...] solve real-world problems. [CBL] is collaborative and hands-on, asking students to work with peers, teachers, and experts [...] to ask good questions, develop deeper subject area knowledge, accept and solve challenges, take action, and share their experience" [1]. The open-ended nature of CBL challenges, provided by external stakeholders, allows learners to be more independent in setting their own goals [11], [12].

Since 2017, research on CBL has increased across various academic disciplines, with a notable focus on higher education in engineering. CBL is frequently used in engineering education [13], as it develops skills for the development of new engineers in a rapidly changing world. These skills include working in multidisciplinary teams, effective communication, conflict resolution, resource management, entrepreneurship, and problem-solving [2], [13]. As such, CBL appears to be well-suited for teaching non-technical courses in computing curricula, particularly those involving innovation skills [10].

While CBL is positioning itself as a teaching and learning approach that responds to the evolving educational landscape, Leijon et al. [13] and Perna et al. [5] alike highlight that there is a need for additional longitudinal and rigorous research across the spectrum. The same sources also point out that many institutions still face substantial troubles in deploying CBL, as the research in this area is still limited and not well-established. The literature also highlights several obstacles to the adoption of CBL, including uncertainty and resistance to change, curriculum alignment, limited time, workload distribution, interdisciplinary perspectives, and ensuring external stakeholder involvement [5].

At FIE 2022, Bombaerts and colleagues hinted at a tension between what they called "structured" and "open" CBL [14]. In the article, the authors defined *structured* CBL as a context where "[the] university [defines] what the important aspects are that have to be learned", and *open* CBL as one where "students [decide] for themselves how much or how little [content the course] should entail". The authors also discuss some trade-offs that ensue from both approaches: structured approaches are easier to assess, more comfortable, and favour depth; open approaches are more demanding, better reflect the wicked nature of challenges, and are more creative.

Last year, still at FIE, we proposed *CYOA*-CBL, a scaffold that aimed to overcome this tension. In our previous article, we outlined a teaching model that can flexibly cater to students with different preferences by reframing the structured/open trade-off from a problem of course design to a student choice [15]. *CYOA*-CBL structures the course in a sequence of "phases", and defines alternative "paths" that students can take. Students have several alternatives to tackle each phase, representing alternative ways to explore solutions to challenges, and may opt to follow a pre-defined path (a structured approach), create their own path and leverage their own knowledge (an open approach), or adopt an in-between solution.

With *CYOA*-CBL, the aim is to redefine Bombaerts' structured/open trade-off as a spectrum rather than as a duality. The goal is also to address the matter of enabling universities to more easily adopt CBL by designing courses with a replicable yet flexible structure.

III. Research goals and pedagogical context

CYOA-CBL divides a CBL course in various phases and steps. While in our previous article we presented the theoretical grounding of the method, *CYOA*-CBL still needed to be tested in practice. We implemented *CYOA*-CBL during fall 2023, in a mandatory four-month (September-December) course at our medium-sized European university. The aim was not only to determine *CYOA*-CBL's feasibility, but also to verify whether students understood the new course process. Indeed, *CYOA*-CBL was initially designed to address the challenges associated with the heterogeneous student population in the same CBL course, as detailed in Section II. This study explores whether students seized the opportunity to customize and personalize their course experience according to their

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needs and challenges by autonomously "choosing their own adventure".

To do so, we adopted *CYOA*-CBL in a course called "Innovation and Entrepreneurship Studies" (I&E Studies) at the University of Trento. This is a 6-ECTS mandatory curricular course designed for second-year Master's students in Computer Science (CS) who are following a curriculum that integrates CS with Innovation and Entrepreneurship (I&E). For the purpose of this study, the course involved 54 second-year CS students and it served as the final course of their "minor in I&E" in their Master's programme. Half of the class was from a double degree program called *EIT Digital Master School*[1], which combines digital competencies with practical skills in I&E, while the others were students from a degree in ICT Innovation, or Erasmus students.

The course in which we deployed *CYOA*-CBL uses CBL since 2018, dividing students into teams and asking them to address a challenge proposed by an external stakeholder. During the course, teams must identify and address the challenge within the context of their assigned case, such as considering alternative business models for a technological startup or analyzing go-to-market scenarios for the launch of a digital product. Students are required to ground their reflections by exploring specific areas like the business environment, competition, suppliers, partners, environmental and sustainability issues, etc., using both deductive methods (i.e., through desk research) and inductive methods (i.e., through field work) as appropriate. This approach allows them to apply knowledge gained throughout their academic careers, particularly concepts related to I&E, to real-world problems.

In this edition of the course, students were divided into 12 teams of 4-5 members each, assigned to challenges presented by 7 external entities, mostly start-ups.

Following our previous article [15], we divided the course in six phases, as described in Fig. 1. In each phase, we organized two main activities: a tutorial and a mentoring session. The tutorial took place first and consisted of a regular two-hour class slot. During these sessions, teachers explained the main concept of the phase and proposed to the students small exercises to help them address the phase, that could be started in class, and continued at home. The week after each tutorial, teams attended mentoring sessions of 30 minutes, where the student team met with a pair of teachers. During mentorings, the team presented their work to the teachers, and students had the opportunity to discuss any issues, receive feedback, and reflect on their progress. The mentoring sessions were guided by "mentoring worksheets", which served as both a checklist for students to ensure they had fulfilled all requirements for the phase, and as an assessment tool. Worksheets contained guiding questions such as "Have you completed the suggested exercise for this phase?" or "Have you written a short meeting agenda with new content questions for the Challenge Provider?" and were common to all groups.

[1]https://masterschool.eitdigital.eu/

The course started, in phase 1, with a case presentation session, during which the Challenge Providers (CPs) described their challenges to the students, shortly followed by a class where students formed teams and bid on what challenges they wanted to work, while ensuring that each challenge had at least one team assigned to it.

The course closed at the end of January, when each team prepared a 10-minute presentation of their solution proposal and submitted a final report detailing their work. For the report, we provided a template with suggested sections, but students were encouraged to modify the report's structure to align with the work they actually performed during the course.

IV. Methods

This article presents results we acquired from a qualitative study where we used mixed methods of data collection to evaluate *CYOA*-CBL. This study is characterized by the collection and analysis of survey data, followed by the collection and analysis of interviews [16] (see Fig. 2). The structure of the study follows a sequential explanatory design, aiming to use the interview data to provide a deeper understanding and explanation of the surveys' findings.

This design consists of two distinct phases, similar to the approach used by Doulougeri et al. in a study on factors influencing students' experience with CBL [17]:

1) an anonymous *group-based phase survey* delivered at the end of each phase of the course, providing a general understanding of students' comprehension of the process;
2) in-depth *semi-structured interviews* to further refine and explain the results by delving into students' views in more depth [16], [17].

In addition to this, we added an anonymous *individual survey at the end of the course* to gather general impressions on the course and validate the results that we had from the phase surveys.

The logic of phase surveys follows the approach of [18] to evaluate a framework for a CBL course. Their primary objective was to gather reflections on what students learned or struggled with, assess the effectiveness of tutorials and mentoring sessions, and determine which path they followed.

The sample population for phase surveys included the total number of teams in the class (this year, 12 groups) and the survey was filled as a group (teams decided one group member to complete this for everyone) at the end of each single phase, resulting in a total of 6 surveys for each of the 12 teams. The survey consisted of closed questions on a 5-point Likert scale ranging from strongly disagree to strongly agree, along with short open-ended questions. The open-ended questions used the following prompts:

- In one word, what did you learn the most during this phase (tutorial and mentoring)?
- In one word, what did you struggle the most with during this phase (tutorial and mentoring)?
- In one word, what would you have done differently in the tutorial/mentoring for this phase?

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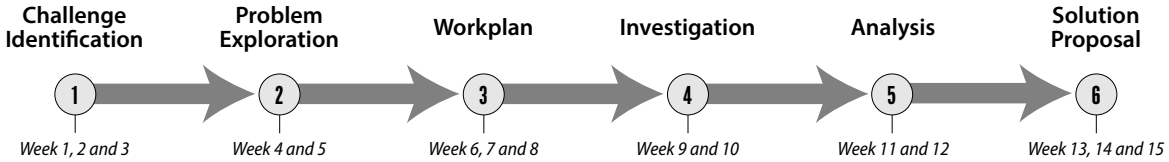


Fig. 1: The division of the course in its six phases, marking what course weeks corresponded to each phase.

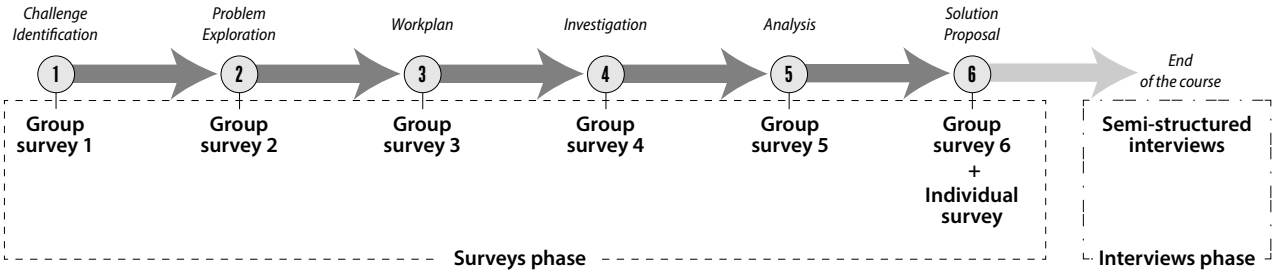


Fig. 2: Mixed methods of data collection.

The questions were designed based on [19] and adjusted to fit the context of this research.

The second survey was given to all students at the conclusion of the course, with each student completing it individually. We received 19 answers out of 54 students, putting response rate at around 35%. The aim of this survey was to assess different course components in a 5-point Likert scale, similar to the previous one, ranging from strongly disagree to strongly agree.

The semi-structured interviews were conducted at the end of the course with a subset of students who voluntarily agree to participate in this study. These interviews were organised after the evaluation process and exam to avoid conflicts of interest. Students did not receive any course credit or any incentive for consenting to data collection, and they did not have any penalty for declining to participate in the study.

We conducted a total of nine interviews, using judgmental sampling as the process of selecting the student population. We chose this sampling technique to remain within a reasonable time constraint while ensuring that we reached a diverse population of students [20]. Interviewing all students in the course would have been not feasible, and random selection might have resulted in clustering of students with similar profiles or, for example, students from the same team. Therefore, we chose to select participants ourselves to ensure a diverse sample based on the following criteria:

- gender;
- course track;
- origin county;
- grade obtained in the course;
- experience during the course (online or in presence or hybrid);
- assigned mentor;

We opted to use these criteria to attain a comprehensive representation of the diverse types of students and their respective experiences encountered this year. While these criteria encompass only some of the factors distinguishing one student from another, they seemed appropriate at this stage for us to delve more deeply into the survey results, which we summarise in Table I.

Criteria	Factor	Students
Gender	Male	4
	Female	5
Course track	ICT innovation	4
	Data Science	2
	HCID	1
	Fintech	1
	Business (Erasmus)	1
Origin country	Italy	4
	Other EU country	4
	Non-EU	1
Grade	$>$ 25/30	7
	$\leq$ 25/30	2
Attendance mode	Fully onsite	6
	Fully online	9
	Hybrid	2
Mentor	Mentor 1	6
	Mentor 2	2

TABLE I: Interview sampling.

Participants were encouraged to discuss their experiences with the course and the *CYOA*-CBL methodology overall. We asked about their challenges throughout the course, how

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they worked and structured their process and their thoughts on the various activities within the course. Each interview lasted approximately 30 minutes and was conducted in either English or Italian to ensure the students felt comfortable with their native language when possible. Interviews conducted in a language other than English were carefully translated by us without altering meanings or phrases.

In this study, we used the data obtained from interviews to better contextualise the data collected through the surveys. We conducted a thematic analysis of the interviews, identifying recurring themes based on the responses obtained from the surveys, and establishing connections between the data from the two phases [21].

Data source	Data type	Coverage
Phase surveys	group survey	6 surveys per 12 teams
Final survey	individual survey	19 out of 54
Post-course interviews	individual interviews	9 out of 54

TABLE II: Data source, type and coverage.

A. Limitations

This study is subject to the context in which it has been developed. The results obtained could be influenced by the type of course, students curricula, and the university context. More tests of the *CYOA*-CBL approach need to be done in order to have a proper understanding of the possible limitations and problems with this new structure.

The results obtained from the final survey are limited to 19 out of 54 students involved in the course. This means that the answers may only partially represent the students' opinions and understanding about the course. We recognise that the study's sample size is not large enough to generalize the results to a broader population.

The results obtained from a study using the judgment sampling method are subject to bias. Samples are selected based on an expert's ability to choose suitable participants, and biases are typically significant factors to consider. The limitations of this method restrict the types of statistical analyses that can be performed with the data [22]. However, in our case, we did not intend to conduct statistical analyses on the responses obtained from the interviews. Instead, the interviews served to confirm (or not) and delve deeper into the responses gathered from previous surveys.

V. Results and discussion

Our multiple sources of data let us gather insights in several different design elements of the *CYOA*-CBL method, that we now illustrate.

A. On teams taking structured or open approaches

In each phase's survey, we asked students what path they were following. By combining the responses of the teams for each phase, we have seen how some groups followed a clear linear process where they stuck with the same path (which we take as a proxy of the students following a *structured* approach), while others changed direction and paths more frequently (which we take as students opting for an *open* approach).

Three out of twelve teams adopted a structured approach, while the others opted for an open or in-between approach. For instance, Team 5 started its work with a business-oriented path but later changed direction to a technological analysis, whereas Team 11 started with a market analysis/scenario collection and concluded the project with a communication strategy. All in all, three teams never changed paths; six teams changed paths once; two teams changed paths twice, and one team changed paths three times. Notably, even the teams that changed paths multiple times never did so in two consecutive phases.

The inclination for either an open or structured approach was confirmed in the interviews. For example, the surveys showed that Student 3's team followed an open approach: while initially they described their path as "market analysis", they changed it to "business modelling" in phase 5, and later changed it again to "collection of scenarios" in phase 6. This was confirmed by the interview: "we stuck to the same [path], but we had some variation towards the end when we found more relevant data.".

Instead, Student 7's team had a structured approach to the process, following a "market analysis" path throughout the entire course. In the interview, Student 7 highlighted how, though the team consistently followed a path, they felt free to choose what their path was to begin with: "We stuck [to the same path] from the beginning [but] I was surprised by the fact that we didn't really have to do a business model during the course. [The course] was more open [...] we weren't expecting to have [the possibility of doing a marketing strategy].". In spite of this, Student 7 stated that it was clear during the whole course that they were free to change paths.

In all interviews, students clearly understood that they could, at any time, change path. Student 3 confirmed that his group "felt quite free", and that "it's more like what the expectations that we had as a team more than what the professor or the course had upon us.".

Student 1 explained how they changed path more than once during the process. In the beginning, the team narrowed down two options, and chose one of the two. However, after collecting some field data, the team understood it was not the right decision, and shifted to the other option: "Let's say, perhaps our mistake was assuming that was the right way to go.". After they realised this, in the 5 phase, the students changed their path and followed it until the end.

B. On changing directions, and the overarching CYOA-CBL structure

The possibility of choosing directions was appreciated by the students even if, as Bombaerts et al. said in their study, an open approach gives student a more demanding experience from a creativity point of view [14]. Echoing these feelings, Student 4 said: "[...] you could spend time on the things you want. [...] And of course, that needs creativity. So it was nice to brainstorm and be a bit more creative instead of like just study from the books. So I really like that about the course.".

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At the same time, students realised that the course's overall curated structured helped them make sense of what was expected of them. Student 9 said: "I admit that having the structure like that certainly helped a bit because you had the stakes marked, so you weren't too free to get lost who knows where.". Student 8 also said: "If we had been freer, there would have been the real risk of taking a direction very far from what you actually want, and the risk of digressing. But if it had been more detailed, they would have left us little space to do what we wanted. [The proposed structure] was a good compromise.".

We summarised in Figure 3 the number of teams that chose a specific path during the various phases. Most of the teams followed a "business modelling" or "market analysis" path though, by looking at final reports, we can see that teams on the same path used different tools during the same phases to complete their work. For example, when performing a market analysis, one team used a combination of strategic interviews and surveys while another relied on desk research looking for example about market size and market dynamics. We take this as a confirmation of the fact that teams understood that they could tune paths to adapt them to their challenges. Student 8 said: "Even in the final report, we indeed added sections and removed some that did not fit our work. So we always adapted, trying to follow the instructions well or poorly, but we adapted to our case.".

In the final survey, 73% of students rated their understanding of the process and "next steps" as 4 or 5 in a 5-point Likert scale. Indeed, during the interview, Student 3 said: "It was actually the first time that I've ever done a course fully digital [...] you have to take a lot of responsibility yourself. And you have really have to plan it in a structure, how you're doing it. [...] But I think the instructions were very clear.". Student 8 reinforced this: "We followed exactly the worksheet that was provided to us and then adapted it to what we had done, but yes, there were never any major doubts about that.".

In the final survey, students indicated the recurring structure of mentoring and tutorials, along with the flexible nature of the course, as strengths that satisfied them. One student wrote: "The main strength is the flexibility and dynamic nature of the course structure.". Someone else added: "The course was conducted in a structured way since the beginning; [however] it really felt like we own the course and there was a sense of extra responsibility.". This positive assessment was then also mentioned during the interviews. Student 5 explained how the mentoring sessions conducted every two weeks helped the group to work "each and every week" because they had to "inform you [the mentors] about what we developed and what we decided to do". This student also explained that with other courses, they could do all the work in the last weeks of the course, whereas with such a course utilizing mentoring sessions, they had to work throughout the entire course period, which helped them maintain high motivation.

This constant work on the challenge helped the students feel less pressure about the final delivery. Student 5 said: "I didn't feel that much pressure [...] because when you are working every week, and you have a work progress in line, then you don't feel too much pressure all of a sudden.". Student 1 added: "I wouldn't say there was pressure because we also had quite involved company mentors who were always there to support us and offer advice. Plus, we could delve into the challenge at our own pace throughout the whole process.". Finally Student 8 explained: "We also completed all the optional tasks [proposed by the mentoring worksheets] to stay ahead. Indeed, they proved to be very useful for the final report.".

C. On tutorials, a controversial activity

From the survey we could gathered some points of improvements. 57% of the students rated the effectiveness of the tutorials in helping tackle the group project as 3 or less in a 5-point Likert scale. Some of them, highlighted in the survey the need to improve the tutorials, suggesting that tutorials should be used to teach specific new knowledge which, as of this year's implementation, was instead taught through supporting material.

We tried to investigate more this issue during the interviews process and we noticed that there are some controversial opinions about the tutorial sessions. For example, Student 5 said: "we had really good conversations during the tutorials. So I think tutorials are the best part of the course, where we can share [our ideas] with our group mates.". Students 6 said: "what I like about the tutorials were that we had some activities to do by group and that was actually the part that I liked the most during the I&E studies.". From the interviews we could understand how tutorials can be used from less motivated groups as an activity to progress with their projects. However for more structured teams, these tutorial were less useful as observed by Student 8 who said: "I didn't fully understand the point of working in class [during tutorials] because then we always did it again at home in a more thorough way. For our group, doing the in-class part wasn't particularly useful, especially because if a member was absent, it was a disaster. [...] For me, they should be more frontal lessons.". Another example was Student 9 who said: "[tutorials] led us to do group work right there during the classes, and it helped us a lot" even if in the end "they were less useful because we found ourselves ahead with the work" but "on one hand it was better this way rather than being too repetitive with already covered theory.". From the interviews, we could say that three students out of nine interviewees would keep the tutorials as they are, while the others would change them, adding more theory and traditional lessons to the course. These different opinions could be explained not only by the different intrinsic motivation of the students but maybe also by the different challenges. Student 4 stated: "I would give it more content [but] I think it's very difficult [to decide] because every group has their own challenge, their own work and their own timeline.".

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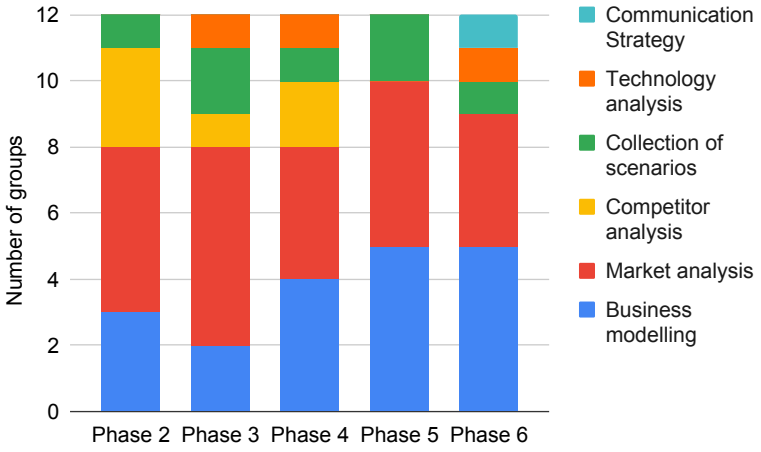


Fig. 3: Groups and paths.

VI. Conclusions and Future Work

In this contribution, we presented the results obtained from a CBL course employing our previously proposed *CYOA*-CBL approach, with a focus on analyzing reflections on the students' experiences.

As we discussed in Section II, the literature previously highlighted CBL's potential in fostering professional skills development in students, though literature also emphasized the challenges inherent in CBL from the perspective of staff and students alike [14]. As CBL exposes students to real challenges and the ambiguity of real-life, students need to have a positive experience throughout the course, allowing them the freedom to explore the challenges while also providing necessary support and guidance when needed [23].

The educational environment in the engineering fields is shifting more than ever from traditional educational towards student-centred approaches to enhance the students' learning experience [3], [24]. Thanks to *CYOA*-CBL, in this course, we observed how students could define their own experiences and processes, personalizing their course and approaching challenges from angles closer to their interests.

In our research, students stated that *CYOA*-CBL provided them with the freedom to be creative while maintaining a structure to avoid losing direction and becoming overwhelmed by the complexity of the challenges. With this preliminary study, we received a first hint on how *CYOA*-CBL may foster an empowering learning environment, offering appropriate teaching and support processes where individuals can personalize their experiences to match their needs and objectives. We also observed how students differ from one another. During this experience, we saw a balance between teams of students who favored a structured approach and those who adopted a more open-ended one. This diversity is also evident in the students' final reports, where the teams decided to change the structure of their reports to fit their chosen approach, leveraging the self-tuning possibilities embedded in our methodology.

Thanks to this study, we also gained insights on what can be improved in *CYOA*-CBL. We learned, contrary to our initial expectations, that structured tutorial sessions and in-class moments are valued by the students. Once again, the diverse needs of the students should be considered when designing course content and activities: in-class moments have proven to be relevant for students who require scheduled time to work with their teammates and engage in predefined activities or exercises. Moreover, more open and organized teams prefer additional content alongside these activities to further explore specific topics. In the upcoming iterations of the course, we aim to strike a balance to meet both legitimate requests from the students.

We plan to re-implement the course in the Fall 2024 semester, gather additional feedback from the students, and refine our process. Our aim is to change as little as possible compared to the implementation reported in this paper, while actively seeking to avoid the problems identified here, addressing critical aspects such as the content of the tutorials. We also hope to enhance this study by increasing the number of interviews conducted at the end of the course, while introducing an assessment phase for the teachers and staff involved in the course to also gather their prospective. We expect this change will give rise to its own challenges but, given the current research landscape where students' perspectives dominate the narrative of teaching and learning, we think gather the teachers' perspective is a much-needed addition.

Then, we propose a reflection about the possibility of integrating iterative student delivery in *CYOA*-CBL. Iterative delivery, where students gradually improve a draft of their final deliverable, and receive teacher feedback multiple times within a single course, is a common feature of many collaboration frameworks, particularly in engineering and computing education, for example with the Agile methodology [25]. We believe that incorporating this iterative characteristic could enhance the course's process, introducing a reflective phase and

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providing students with opportunities to refine their projects further.

In conclusion, through the insights gleaned from student feedback and interviews, we have gained valuable perspectives on tailoring educational experiences to meet diverse learning needs. While more research needs to be conducted in order to address the gaps still associated with CBL, we lean towards agreeing with Doulgeri et al., who suggest that CBL shows promising benefits when integrated at the course or curriculum level [4]. *CYOA*-CBL can be seen as one of these initiatives that aim to foster students' autonomy and empowerment, paving the way for further advancements in education.

VII. Acknowledgment

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Appendix E

Paper E

Strategies for Implementing Challenge-Based Learning in Short Courses: Developing Professional Skills Through Challenges

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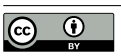
Abstract

Challenge-Based Learning (CBL) is an active learning methodology that engages students in solving authentic, real-world problems while fostering collaboration, creativity, and critical thinking, and it has become particularly popular in computer science education. The adaptation of CBL designs across different educational contexts, however, remains challenging, not defined in the literature, and underexplored in practice. This work builds on a previous CBL framework called "Choose Your Own Adventure in CBL (CYOA-CBL)", designed to enhance flexibility and adaptability across educational contexts. The aim of this work was to investigate whether a CBL approach, originally designed for a full semester course, could be effectively adapted into a four-week extracurricular activity while maintaining its pedagogical integrity. The activity combined one in-person week with three online weeks and involved 20 master's students working in small teams. Overall, this study provides support for CBL's successful implementation in short extracurricular contexts and highlights practical strategies for educators seeking to integrate CBL into short-format or micro-credentialled courses, contributing to the ongoing discussion on skills development through active learning approaches in computing education.

CCS Concepts

• **Social and professional topics** → *Computing education programs*; **Computing profession**.

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1 Introduction

The Computing Curricula 2023 report states that graduates should develop essential skills such as problem-solving and analytical reasoning, as well as professional dispositions like teamwork and adaptability [4]. These abilities are fundamental not only for success in the workplace but also for long-term professional growth and effectiveness. In this context, Challenge-Based Learning (CBL) is gaining popularity among the active learning methodologies and other *X*-Based Learning [1] as it engages students in solving authentic, real-world problems while fostering collaboration, critical thinking, and creativity. In computer science education, CBL has been described to be particularly valuable, since it enables students to connect theoretical knowledge with practical application while developing transversal skills and professional dispositions [3, 7]. One of the challenges of deploying CBL is that course design is significantly more complex. A course with similar objectives, for example, is not immediately adaptable when moving between different educational contexts such as from a semester-long curricular course to a short-term extracurricular activity. As a response to this problem, our team previously worked on "Choose Your Own Adventure in CBL" (CYOA-CBL) to enhance the adaptability of CBL across educational contexts, while minimizing the resources needed for implementation [5]. With the growth of flexible learning formats such as micro-credentials, there has been increasing interest in models capable of delivering meaningful learning experiences within limited timeframes [8, 9]. However, most of the literature on CBL in computing focuses on long-form implementations, leaving open the question of whether (and how) a CBL approach designed for a semester-long course can be adapted to a condensed format. In this work, we explored whether such CYOA-CBL could be effectively transferred from a six-month course to a four-week extracurricular activity, while maintaining its pedagogical integrity.

2 Pedagogical context

Our intervention took place within an extracurricular activity organized at the University of Trento as part of an initiative promoted by the ECIU Alliance, a consortium of 13 European universities that focuses on teaching through CBL. The activity awarded 3 ECTS credits and was open to Master's students from various disciplines, although its learning objectives focused on strategic planning, teamwork, and effective communication, aligned with the skills identified as essential for computer science professionals [2]. Participants

came from mixed academic backgrounds and enrolled voluntarily by submitting an application and a letter of intent. The four-week program included one week of in-person activities followed by three weeks conducted online. A total of 20 students took part, organized into four teams of five members each. The challenge was proposed by Park World Tour Italia Orienteering Club, as orienteering is known to foster transversal skills such as problem-solving [6]. Students were asked to engage with orienteering and identify social benefits that the sport and the club could generate beyond athletic performance. The challenge was co-designed by the club's management in collaboration with the teachers responsible for developing and implementing the activity. We collected anonymous individual feedback at the end of the course and group feedback after each phase of the process through short open-ended questions. This dual-level feedback approach, for which we are still analysing the data, allowed us to capture both personal reflections on the learning experience and team-based insights of the CBL process.

3 Methodology

To adapt the CYOA-CBL approach to the short duration of the activity, we condensed the six phases of CYOA-CBL into two main stages: three phases were conducted during the in-person week, while the remaining three phases were completed online over the following three weeks. We conducted five mentoring sessions: three in-person during the first week and two online in the subsequent weeks. The students particularly appreciated the personalized feedback provided by mentors along the process. The so-called "mentoring worksheets" were used only to prepare the online mentoring sessions and support structured progress. In contrast, during the in-person week, mentoring sessions were intentionally less structured to allow more open discussions based on each group's progress. The so-called "tutorials" of the CYOA-CBL framework were maintained only during the in-person week, and no new content was introduced during the online phase, allowing participants to focus entirely on challenge development. Additionally, students attended lectures delivered by experts in orienteering, sports, and technology, and had the opportunity to experience orienteering through two practical sessions using maps and compasses. All online activities used Miro as a collaboration platform to facilitate coordination and communication among team members. Finally, the final deliverable was simplified to a presentation of the team's proposed solutions and reflections, since evaluation was conducted on a pass/fail basis.

4 Conclusion and future work

The key adjustments in this short CBL experience, compared to the curricular course, were primarily related to time constraints and the balance between in-person and online activities. The division of phases was designed to begin the challenge in person, allowing teams to meet, interact with the challenge provider, and conclude the first week with a defined work plan, before continuing online with clear goals for each week. However, feedback revealed that students would have preferred the opposite order: starting online and concluding the challenge in person. This insight suggests an interesting direction to explore in future iterations.

Weekly mentoring sessions proved crucial in maintaining group engagement and ensuring progress, particularly within the short timeframe. In condensed CBL implementations, frequent checks help prevent students from feeling lost in the ambiguity of open-ended challenges. Even in this short activity, mentoring worked very well, and these structured and regular feedback moments were highly appreciated by students across different contexts. Similarly, a well-defined structure was valued by participants and proved essential to support them through this intense CBL experience.

A limitation of the current implementation is the lack of an objective means to evaluate the gained skills. Due to the limited duration, it is difficult to achieve the same level of depth as in longer curricular courses. However, when viewed through the lens of micro-credentials, this type of short CBL experience can be particularly useful for developing specific competencies such as teamwork, communication, and critical thinking. Future work should also acknowledge the limitation of the small, self-selected sample size and seek to replicate the study with a larger, more diverse student population to enhance the generalisability of the findings. A potential future direction is to investigate how to design effective assessment methods for these transversal skills within short-term implementations to provide more grounded metrics for skill acquisition.

This work provides a first result suggesting that, by using a pedagogical framework such as CYOA-CBL, teachers can redesign their CBL courses, adapting them to long-term or short-term forms, and to online or in-person formats. Future explorations will focus on implementing CYOA-CBL in hybrid learning environments and within the context of micro-credentials to further validate its adaptability and effectiveness.

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Appendix F

Paper F

Towards enabling learner self-regulation for computer science non-technical course

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Challenge-Based Learning (CBL) bridges academic computer science curricula with professional dispositions, yet educators struggle to implement CBL in computing education. To make CBL more adaptable and adopted to diverse university contexts and student profiles, we evaluated Choose Your Own Adventure – Challenge-Based Learning (CYOA-CBL), a novel pedagogical framework which aim to align course demands with diverse student dispositions while providing instructors with a scalable, replicable framework for CBL course implementations. We evaluated CYOA-CBL using a Mixed-Methods Action Research design across two academic years in a Master's Innovation and Entrepreneurship course at the University of Trento, involving 84 students across 20 teams. Data were gathered via phase-by-phase surveys, a final course survey, post-course interviews, field notes, and digital student artifacts. Results show that CYOA-CBL preserves procedural clarity while enhancing student agency, self-efficacy, and project ownership. Mentoring and structured activities anchored teams through ambiguity. Qualitative analysis revealed that teams exhibit different attitudes toward the course, which can be represented by a two-dimensional matrix defined by process trajectory (Linear vs. Dynamic) and activity scope (Specialized vs. Integrative). Ultimately, CYOA-CBL can offer a scalable framework for computing educators seeking to design adaptive CBL courses.

CCS Concepts: • **Do Not Use This Code → Generate the Correct Terms for Your Paper**; *Generate the Correct Terms for Your Paper*; Generate the Correct Terms for Your Paper; Generate the Correct Terms for Your Paper.

Additional Key Words and Phrases: Xxx, XXx,

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1 Introduction

In recent years, Challenge-Based Learning (CBL) has gained significant traction across higher education institutions as a pedagogical model that emphasizes active, experiential, and collaborative learning [32]. Rooted in real-world problem solving and aligned with 21st-century skill frameworks [19, 40], CBL encourages students to tackle authentic, open-ended societal and technological challenges in direct collaboration with external actors such as companies, municipalities,

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NGOs [32, 45]. The methodology is traditionally structured into three main phases — Engage, Investigate, and Act — guiding learners from broad, abstract "Big Ideas" to concrete, actionable solutions [32, 33]. The adoption of CBL has been particularly prominent in engineering, computer science, and innovation programs, where addressing complex, multifaceted problems requires interdisciplinary mindsets, adaptive problem-solving skills, and active collaboration [3, 46].

Despite its growing popularity, CBL remains an evolving educational framework without a universally accepted standard for design and implementation [24, 35]. Individual institutions and instructors frequently interpret and adapt CBL based on local contextual constraints, disciplinary goals, and available resources [45]. This lack of adaptable, standardized operational guidelines makes CBL challenging to implement, posing a barrier to educators seeking to transform traditional lecture-based computing courses into active, student-centered environments that cultivate both technical mastery and essential professional competencies [20, 45].

Moreover, the widespread adoption of CBL surfaces critical pedagogical and logistical hurdles for both instructors and students [14, 45]. On the instructor side, designing and facilitating CBL courses demands substantial effort to manage the open-ended nature of the learning process, coordinate with external challenge providers, and establish objective assessment criteria [4]. On the student side, transitioning to a CBL environment can be either empowering or disorienting, depending on individual expectations, learning preferences, and readiness for self-regulated learning [16, 27]. In particular, reliance on external stakeholders introduces operational variability and ambiguity that can significantly impact team dynamics and student satisfaction [31, 35].

At the heart of these challenges lies a central tension in CBL course design: balancing instructional structure with student autonomy and openness [4]. As highlighted in prior research [4], an overly structured framework can constrain student creativity and reduce project ownership. Conversely, an excessively open-ended environment risks overwhelming students who lack high levels of self-regulation or psychological tolerance for ambiguity, leading to cognitive overload, anxiety, and disengagement [10, 28, 45]. Classroom observations consistently reflect this tension: while some computing students express a strong preference for guided, highly structured learning pathways, others demand the freedom to explore non-linear, open-ended challenges and shape their own educational trajectory [17, 28]. These diverging needs reveal a fundamental challenge in computing education: how can educators design CBL environments that are inherently adaptive to diverse student dispositions without imposing unsustainable workloads on teaching staff?

To address this challenge, we developed Choose Your Own Adventure – Challenge-Based Learning (CYOA-CBL), a novel pedagogical framework designed to reconcile the structure–openness tension [25, 26]. CYOA-CBL reframes the traditional binary choice between "structured" and "open" instruction into an adaptive, student-driven spectrum. The framework decomposes the challenge resolution process into six sequential phases - ranging from challenge identification to solution proposal - supported by structured learning packages, activity worksheets, and regular mentoring sessions [26]. Rather than imposing a single rigid workflow, CYOA-CBL empowers student teams to select, combine, or customize predefined "paths" (e.g., Business, Technological, Policy, or hybrid trajectories) on a phase-by-phase basis [26]. In doing so, CYOA-CBL aims to foster student autonomy and self-efficacy while preserving the scaffolding necessary to support learners who require more structure [17, 48].

This raises fundamental empirical questions regarding the viability and perception of adaptive scaffolding in computing education: RQ1: Is it possible to design a CBL course in computing education that avoids disorienting students who require structured guidance while remaining flexible for those seeking open-ended exploration? RQ2: Can the CYOA-CBL format serve as an effective response to the need for adaptive learning pathways in challenge-based

environments? RQ3: How is the CYOA-CBL model perceived and interpreted by students with varying dispositions toward learning, structure, and autonomy? In this article, we present a two-year study evaluating the implementation of the CYOA-CBL methodology across two consecutive Academic Years (2023/2024 and 2024/2025) of a mandatory graduate-level course in Innovation and Entrepreneurship Studies within a Master's program in Computer Science at the University of Trento (N=84 enrolled students across 20 project teams). Adopting a Mixed-Methods Action Research design grounded in Concurrent Triangulation [9], we analyze quantitative survey data alongside qualitative interviews, visual students' artifacts, and field observations. Our investigation examines how student teams navigated the CYOA-CBL format, how their underlying dispositions toward autonomy and structure shaped their path choices and engagement, and how iterative refinements to the framework impacted the overall learning experience.

This article is organized as follows: Section 2 reviews relevant literature on active learning, X-Based Learning, and Challenge-Based Learning in computing education, details the core frictions of CBL, and presents the conceptual foundation and architectural design of the CYOA-CBL framework; Section 3 outlines the Mixed-Methods Action Research design, participant demographics across both iterations, data collection protocols, and data analysis procedures; Section 4 details the quantitative and qualitative empirical findings from Iteration 1 and the corresponding findings from Iteration 2; Section 5 synthesizes key insights across iterations, reflects on the theoretical and practical implications for adaptive CBL design in computing education, acknowledges study limitations, and suggests avenues for future research.

2 Background

In recent years, Computing Education Research has increasingly focused on the critical need to bridge the gap between academic curricula and the rapidly evolving Information Technology (IT) industry [8, 46]. Traditional lecture-based, teacher-centered instructional techniques often fail to prepare students for the complex, ambiguous, and collaborative challenges they will face in real-world professional development scenarios [46]. To address this "capability-competency" need Information Technology Curricular 2017, Computing Curricula 2020 and Computer Science Curricula 2023, the most relevant curriculum guidelines from the Association for Computing Machinery (ACM) and the IEEE Computer Society (IEEE-CS) [19, 23, 40] explicitly advocate for a transition toward competency-based learning over traditional knowledge-based teaching models [46].

Consequently, higher education institutions are searching for flexible, adaptive, and personalized approaches to learning that mirror modern industry expectations, opening up to the opportunity for students to develop self-reflection, self-regulation, and interdisciplinary choices aligned with individual interests [50]. In this context, what has further emphasized this evolving landscape is the increasingly easy access to basic academic knowledge online, further amplified by Generative Artificial Intelligence tools [2]. Accordingly, Computer Science (CS) and engineering curricula are emphasizing the importance of adaptive problem-solving, open-ended collaboration, and critical evaluation, in this novel AI-based educational landscape [19, 40].

Despite this clear mandate, widespread instructional change remains slow [18]. Many instructors in Computer Science, Information Technology, and Software Engineering (CS/IT/SE) programs continue to rely exclusively on traditional, teacher-centered methods [8, 46]. This persistent reliance is largely driven by the systemic challenges and historical patterns associated with changing deeply rooted instructional methods within engineering and computing departments and Higher Education in general [46]. While the broader computer science faculty has adopted student-centered practices to some degree with more attention to students diversity, the computing community must strive for significantly higher adoption rates to optimize student retention and learning outcomes [20].

To mitigate these instructional barriers, researchers have experimented extensively with transformational, evidence-based pedagogical models [8, 46]. As documented in computing education literature, evidence-based alternatives to traditional lecturinginvolve students working on interactive tasks that simulate expert reasoning and professional problem-solving while receiving immediate, iterative feedback from peers and instructors [20].

Within this landscape of student-centered experimentation, a prominent family of active learning methodologies is that of so-called *X*-Based Learning (XBL) [3] methods.

XBL, which includes frameworks such as Project-Based Learning (PjBL), Problem-Based Learning (PBL) and Case-Based Learning (CsBL), draws on the core principles of social constructivism, which posit that learning is an active, collective construction of meaning [49]. XBL methodologies prioritize social interaction, the creation of shared artifacts, and close collaboration between actors in the educational space [36]. In computer science education, this active collaboration may serve as a direct bridge to the professional sector, where methodologies like Agile development practices require professionals to work within highly collaborative ecosystems where technical solutions emerge through collective iteration rather than isolated individual effort.

While XBL methodologies share the overarching goal of shifting the focus from passive instruction to student-centered engagement, they differ significantly in their structural starting points, procedural workflows, and intended learning outcomes [45].

Challenge-Based Learning (CBL) emerges as one of the latest and most sophisticated, yet also most demanding, methodologies within the XBL family. Originally proposed by Nichols and Cator, CBL is conceptualized as a multidisciplinary approach that encourages students to leverage technology to solve open-ended, real-world problems [32]. The methodology is inherently collaborative and hands-on, requiring students to work with a variety of stakeholders to take concrete, actionable steps on the ground [32]. Most notably, beyond working with peers and teachers, CBL foresees direct involvement in the educational process of external stakeholders.

In a CBL course, students work in teams, drawing on multiple disciplinary perspectives and taking up a variety of intra-team roles to develop viable solutions to real-world problems identified by external stakeholders and called "challenges". These challenges are proposed by stakeholders such as not-for-profit organizations, companies, public sector institutions, and more, and are connected to the needs of society or external university partners without a predefined solution path, resulting in an open-ended question — hence the name "challenge" — rather than as a predefined problem that needs a univocal solution. Challenges, therefore, consider social implications, not just technical or commercial outcomes, and the CBL process aims to test and implement solutions (e.g., a pilot, service, or product) rather than producing pure coursework deliverables. The role of teachers shifts from instructors to mentors, providing feedback and support while leaving substantive choices to the learners [45].

The typical pedagogical architecture of CBL is built upon a three-phase framework: Engage, Investigate, and Act [34]. These stages closely mirror the iterative cycle of Kolb's Experiential Learning Theory (ELT), which posits that knowledge is continually generated through the transformation of concrete experience into abstract conceptualization and active experimentation [22].

Each phase contains structured checkpoints designed to prepare learners for the subsequent stage:

- Engage: learners move from an abstract "Big Idea" to a concrete and actionable challenge using an essential questioning process. The goal is to personally connect with the content and foster ownership of the challenge.
- Investigate: building from the challenge, learners develop contextualized learning experiences and conduct rigorous, content-based research. This creates the conceptual foundation necessary for sustainable solutions.

- Act: evidence-based solutions are developed and implemented with an authentic audience. The results are then evaluated, combining a desire to make a difference with a demonstration of content mastery.

Ultimately, CBL expects teams to draw on multiple disciplinary perspectives, considering broad social, ethical, and environmental implications alongside standard technical outcomes [45].

Despite the significant theoretical and structural benefits of CBL and alternative "XBL" pedagogies, empirical evidence demonstrates that successful execution is never guaranteed. In computing education literature, a systematic literature conducted by Suleiman et al. [46] established a baseline of the critical challenges faced by students in student-centered, Project-Based Learning (PjBL) environments. While Suleiman et al.'s analysis primarily focused on project-based contexts, their findings are transferable and often intensified in CBL. Indeed, because CBL represents an evolution of PjBL that shares its inductive, collaborative, and open-ended pedagogical foundation, the operational bottlenecks identified in PjBL remain unresolved in standard CBL implementations, a persistence widely confirmed in dedicated CBL literature. According to Suleiman et al. [46], these critical pitfalls manifest across several dimensions: teaching workload, students workload, confidence and motivation, external stakeholders, course organization, project management, teamwork and assessment. These friction points are widely reported throughout CBL research. For instance, Doulougeri et al. [14] identified six recurring student-level difficulties, while Leijon et al. [24] and Perna et al. [36] confirmed that the widespread adoption of CBL faces significant institutional and structural hurdles. Nawawi et al. [31] further noted that while computing institutions increasingly leverage CBL to cultivate creative, innovative, and industry-ready talent, the practical difficulties of execution in higher education remain a major barrier. Crucially, the overall efficacy and success of a CBL implementation depend heavily on sustained student engagement and the learners' collaborative capacity to manage the inherent frictions of working within diverse peer teams [31].

Empirical evidence highlights a strong interdependency between a student's performance in CBL and their prior knowledge, intrinsic motivation [27], and the explicit scaffolding provided by teachers and external challenge providers [29, 45]. A primary point of friction within mandatory engineering and CS curricula is student resistance, driven by diversity in readiness and motivational profiles.

Active learning environments disrupt the traditional "didactic contract" that students expect in higher education [35, 37, 44]. In a standard lecture model, student is a passive actor of the class. In contrast, active learning environments demand high levels of proactiveness, resilience, and a high tolerance for ambiguity [45, 46]. As Felder and Brent [17] documented from their own early attempts, this shift can trigger intense resistance; they observed that the approach initially faced strong aversion from students, with some outright refusing to cooperate and expressing clear hostility toward both the methodology and the instructor. The psychological transition from being a relatively passive receiver of information in teacher-centered lectures to an active, autonomous participant represents a massive developmental hurdle for engineering and computer science students [46]. Due to the high volume activities during the course period required to students, computing students perceive the workload as exceptionally high which can make them feel overwhelmed [46].

This cognitive friction is well documented. Deslauriers et al. [10] showed that students in active learning environments frequently report lower subjective satisfaction and an inferior perceived feeling of learning compared to passive lectures, even when their objective learning outcomes are demonstrably higher. This paradox is driven by an increased cognitive load: active learning requires substantial mental effort, which students frequently misinterpret as poor or disorganized instruction [10]. In CBL courses, this frustration is amplified during the initial stages. Doulougeri et al. [14] identified common pain points, including narrowing down overly broad challenges, navigating internal team dynamics, and

managing self-regulated timelines. In mandatory courses where intrinsic motivation varies and enrollment is required rather than a real choice of the student these difficulties can be exacerbated.

To understand this friction, Self-Determination Theory (SDT) provides a valuable psychological lens [38]. SDT distinguishes between intrinsic and extrinsic motivation: intrinsic motivation refers to engaging in an activity for its inherent satisfaction, whereas extrinsic motivation involves performing an activity to attain a separable outcome (e.g., grades, credits, or avoiding failure) [38]. SDT posits that human development and intrinsic motivation depend on the satisfaction of three basic psychological needs: autonomy (the feeling of volition and control), competence (the experience of mastery and efficacy), and relatedness (the sense of connection and belonging) [39]. When these needs are met, learners are more likely to experience intrinsic motivation and so engaging in learning because it feels meaningful, interesting, or aligned with personal values and goals [39]. While CBL is inherently designed to rely on and foster intrinsically motivated learners rather than passive recipients of information [32], student populations of mandatory engineering courses are highly heterogeneous. Many students exhibit predominantly extrinsic motivational profiles, focusing heavily on grade maximization and strategic compliance. Research suggests that when extrinsically motivated students are faced with the open-ended nature of CBL, they may adopt a "surface approach" to learning, seeking the path of least resistance rather than engaging in deep exploration [42]. Furthermore, recent findings by Michel et al. [30] indicate that behavioral engagement (e.g., investing extra effort, preparing for meetings) significantly predicts students' self-efficacy beliefs. This suggests that confidence in CBL is not just a prerequisite for action, but a result of it. Students who do not actively invest extra effort fail to develop the sense of mastery required for the course, creating a vicious cycle of disengagement [30].

A central friction relates to a student's psychological tolerance for ambiguity. While navigating real-world, ill-defined "wicked" problems helps students build systemic resilience and embrace constructive failure [28], it conflicts with traditional engineering education, which heavily prioritizes well-structured problems with explicit parameters and optimized solutions. Students with a low tolerance for ambiguity frequently respond to the open-ended nature of CBL with severe anxiety. When surveyed on the most frustrating aspects of CBL, students frequently cite high situational uncertainty as a primary source of emotional distress [28]. Many computing learners do not feel comfortable exploring autonomously with minimal guidance, expressing a clear preference for a traditional, predictable course format when faced with high situational uncertainty [46].

This vulnerability underscores the critical role of Self-Regulated Learning (SRL) skills [13]. Because students bear the primary responsibility for planning, monitoring, and evaluating their workflow, a lack of foundational SRL skills can lead to cognitive paralysis, a fear of the unknown and a lack of control [16]. To prevent such outcomes, Jerome Bruner and colleagues introduced the concept of scaffolding in education to prevent learners from becoming overwhelmed [51]. Scaffolding involves temporary support, such as guided prompts, expert tools, or peer collaboration, that helps students tackle tasks they cannot yet do independently. This support bridges the Zone of Proximal Development (ZPD), a key idea from Lev Vygotsky's social constructivism theory [6, 48]. By addressing the ZPD, educators provide the necessary assistance to guide students turning potential frustration into a constructive learning experience [52].

This dynamic creates a continuous challenge for curriculum design in CBL and other active learning courses in computing education. As discussed by Bombaerts et al. [4], instructors face a fundamental trade-off between "structured" and "open" CBL approaches. Structured approaches are easier to assess, more comfortable, and favor depth while open approaches are more demanding, better reflect the ambiguity of real-world challenges, and encourage creativity.

Currently, the choice between these approaches is made by instructors during the course design phase, before the course begins and without prior knowledge of the students. This can be problematic, as the selected approach may not

align with students' motivations or learning preferences, potentially impacting students' engagement and effectiveness. Students have diverse needs, highlighting the importance of personalized and adaptive learning environments to effectively support them [21]. A one-size-fits-all approach fails to address the wide range of student dispositions in a CBL course.

In such learner-centered classes, a stark contrast often emerges: while some students thrive in open-ended and autonomous settings, others require a highly structured approach and explicit guidance. This friction frequently manifests as resistance to student-centered learning. Students who are accustomed to traditional instructional models, rarely appreciate having this support suddenly withdrawn, and some may even perceive the shift in teaching as a threat [17, 43]. While XBL pedagogies possess strong potential to enhance student motivation via real-world grounding and collaboration, students can easily and rapidly lose motivation and interest due to the challenges they face and a perceived lack of support [46]. Consequently, a successful CBL environment requires a balanced combination of autonomy and scaffolding. If instructors provide sufficient structure and guidance along the way, most students will eventually overcome this initial resistance, reaching satisfactory levels of both academic performance and acceptance of responsibility for their own learning [17].

Therefore, creating tailored and supportive learning experiences is crucial, as enhanced engagement consistently leads to better outcomes [29].

2.1 Study objectives, aims, and research goals

Because the standard implementation of CBL has not find yet a clear solution to overcome the challenges of workload and motivation identified by Suleiman et al. [46], there is an urgent need to design and evaluate novel, adaptive architectures of CBL courses within computing curricula. This study addresses the challenge to provide stimulating, realistic, and autonomy-driven learning experiences without disorienting or frustrating students who require more structured guidance. The fundamental premise of this research is that the same educational activity can be highly meaningful or largely unsuccessful depending on the students' attitudes and personal dispositions, rather than just the content or the intrinsic quality of the instructional design itself. Consequently, there is the need to explore flexible, adaptive formats that enable autonomous personalization of the learning experience.

Building upon the initial framework of the Choose Your Own Adventure (CYOA) approach to Challenge-Based Learning (CBL) presented at Frontiers in Education 2023 ans 2024 [25, 26], the primary purpose of this study is to analyze the outcomes of this novel framework evaluated across two distinct iterations. CYOA-CBL is a pedagogical framework that proposes a novel approach to CBL by reconfiguring the traditional duality between "structured" and "open" CBL into a flexible spectrum where students can place themselves based on their preferences. The model breaks the course design down into six sequential phases - challenge identification, problem space exploration and goal-setting, work plan definition, investigation, analysis, and solution proposal(s) - guiding teams from initial scope definition to final outcomes. These phases are supported by learning packages, common activities checklists called "worksheets" and mentoring sessions. As illustrated in Figure 1, teachers establish predefined "paths" (or "adventures") tailored to specific outcomes, but empower student teams to choose their own trajectory: following a guided path, mixing paths on a phase-by-phase basis, or designing custom activities. By making course structure a student choice rather than a rigid instructional constraint, CYOA-CBL aims to align course demands with diverse student dispositions while providing instructors with a scalable, replicable framework for CBL course implementations.

The specific target audience for this intervention consists of master university students enrolled in a mandatory, curricular Computer Science course on Innovation and Entrepreneurship. Specifically, the study aims to investigate

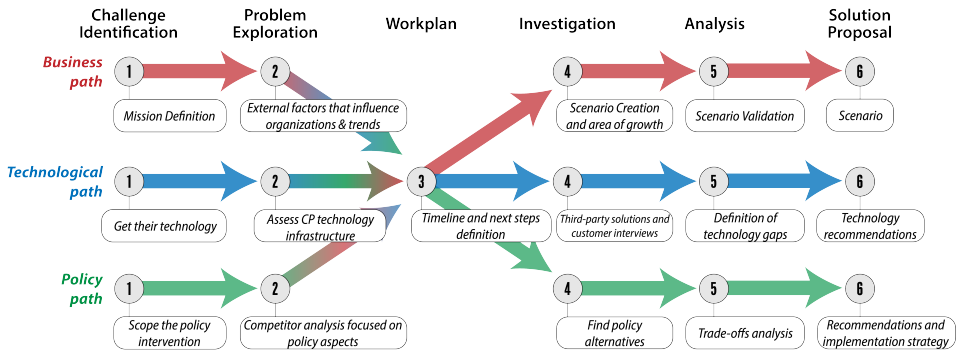


Fig. 1. Structure of the CYOA-CBL framework with the six phases and three exemplary paths (Business, Technological, and Policy) with their respective phase-by-phase activities.

whether and how a flexible instructional format can offer sufficient structure to students who require it, while simultaneously guaranteeing autonomy and openness to those who prefer real-world, non-linear challenges. Furthermore, it seeks to explore how this model organically adapts to diverse student profiles and attitudes toward learning without necessitating direct intervention or additional workload from the instructor.

To investigate this complex educational phenomenon, this study adopts a mixed methods design. This methodological choice allows for the synergistic combination of a descriptive approach with an interpretive approach, aligning with the dual research goals of empirical description and deeper understanding. The descriptive dimension focuses on path mapping and pattern identification by analyzing the specific CYOA pathways selected by students and exploring whether coherent patterns exist between these choices and students' underlying attitudes toward the course. Moving beyond these structural patterns, the interpretive dimension evaluates the adaptability and perception of the model, assessing the overall potential of the CYOA format as an adaptive educational tool within CBL ecosystems by interpreting how the model is experienced by students with varying dispositions toward learning, structure, and autonomy.

To address these objectives, the study is guided by the following research questions:

- **RQ1:** Is it possible to design a CBL course in computing education that is not disorienting for students who need more guidance, but still flexible for those who want to explore open-ended challenges?
- **RQ2:** Can the CYOA-CBL format serve as an effective response to the need for adaptive learning pathways in challenge-based environments?
- **RQ3:** How is the CYOA-CBL model perceived and interpreted by students with different dispositions toward learning, structure, and autonomy?

3 Method

3.1 Research design overview

To address the research questions, this study adopts an iterative Mixed-Methods Action Research design. Specifically, it follows the Concurrent Triangulation Design principles [9], allowing for the simultaneous collection and subsequent integration of quantitative and qualitative data, with qualitative interviews embedded to enrich and contextualize the primary findings.

In alignment with Action Research principles [1], the study was executed across two distinct and sequential iterations. This strategy allows the research team to analyze data from the first cycle to implement improvements for the second.

The study was situated within the higher education context at the University of Trento, specifically within a mandatory and curricular computer science course for Master's students. The investigation spanned two academic years—2023/2024 (Iteration 1) and 2024/2025 (Iteration 2) during which the novel Choose Your Own Adventure - Challenge-Based Learning (CYOA-CBL) educational framework, presented above, was implemented.

In all iterations, quantitative data were collected through structured surveys given to student teams at the end of each of the six CYOA-CBL phases, as well as through a final individual survey at the conclusion of the course.

To add context to these quantitative results and gain deeper insight into the learning process, qualitative data were continuously collected from five sources: open-ended survey questions for teams at the end of each CYOA-CBL phase; final open-ended survey questions for individuals at the end of the course; observational notes taken by researchers during class sessions; digital artifacts created by student teams using Miro; in-depth individual interviews conducted at the end of each course iteration with a voluntary group of students.

Rather than analyzing datasets in isolation, an iterative, interpretive analysis was employed to synthesize the findings. Descriptive statistics were used with the Likert-scale survey data to provide an initial overview of student satisfaction and understanding of the process. Thematic analysis [41] was applied to both the open-ended survey responses, the observational notes and the interview transcripts. This process initially used a deductive approach followed by an inductive coding approach [5], allowing existing theories to be investigated alongside critical themes regarding student narratives, challenges, and adaptation strategies that emerged directly from the data. This offers the depth needed to uncover the underlying reasons, mechanisms, and dynamics of students' experiences. The datasets of each iteration were integrated using a concurrent triangulation strategy. By cross-examining and merging the descriptive quantitative statistics with the qualitative themes, the study achieves a multi-faceted understanding of how the adaptive scaffolding impacted student learning. This integration serves to validating quantitative trends through narrative evidence and extending the scope of inquiry by capturing emergent themes from multiple perspectives and at different stages of the process that surveys alone could not measure. Additionally, the two iterations were used to improve the reliability and validity of this research and to discover other potential interesting points of discussion.

3.2 Researcher description

The researchers involved in this study are the same individuals who conceptualized and designed the CYOA-CBL framework. Their expertise in CBL is grounded in years of practical implementation, having adopted CBL as the core pedagogical approach in multiple higher education courses since 2018. This extensive background provided the team with a deep, pre-existing understanding of CBL's structural strengths, operational limitations, and the recurrent challenges students face during its implementation.

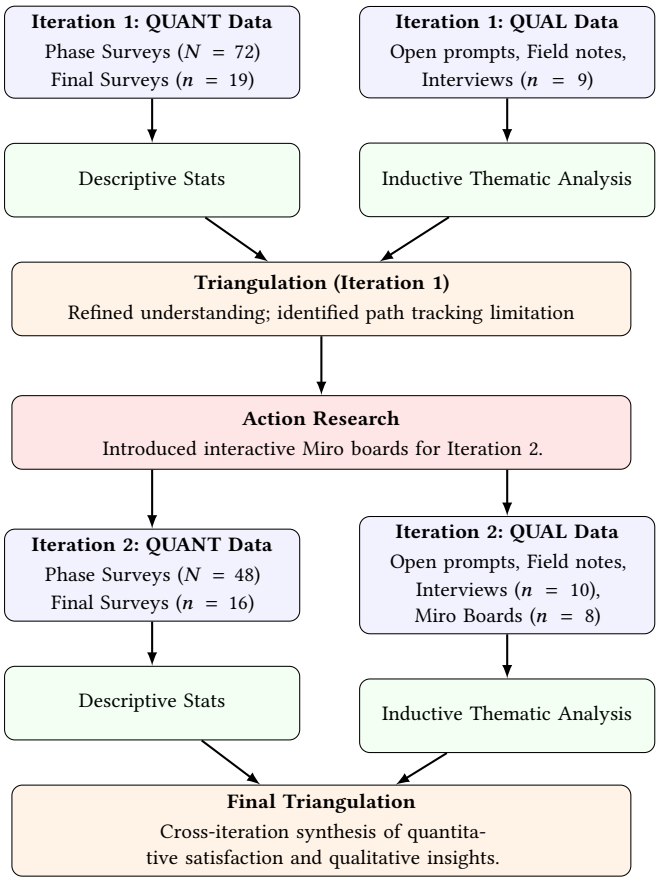


Fig. 2. Methodological overview of the Concurrent Triangulation Design within the Action Research cycle.

Given this dual role of the researchers as both curriculum designers and evaluators, the focus of the study was placed on understanding students' experiences and perceptions of the CYOA-CBL process, rather than evaluating instructional practices or teacher performance.

While the researchers' deep familiarity with CYOA-CBL design logic allowed them to formulate highly targeted interview prompts and detect subtle nuances in student narratives, it also carried the risk of confirmation bias.

This insider perspective offered several advantages during data collection and analysis. Familiarity with the CYOA-CBL framework allowed researchers to formulate more targeted interview questions and interpret nuanced aspects of students' responses related to CYOA-CBL's design logic. At the same time, to mitigate power dynamics and social desirability bias, several strategies were adopted: surveys were anonymized and administered before final grades were assigned, and all interviews were conducted after the course had concluded and grades were finalized, ensuring that student feedback was uninfluenced by evaluation concerns.

The researchers' prior knowledge also influenced the coding process in qualitative analysis, as it allowed them to recognize subtle patterns in student narratives. To mitigate the risk of confirmation bias, themes were first identified

through deductive thematic analysis to examine pre-conceptualized theoretical concepts, followed by an inductive thematic analysis to identify emerging themes [5]. Rather than forcing the data exclusively to predetermined theoretical categories, additional themes were allowed to emerge directly from the raw text. This hybrid approach enabled the team to leverage our domain expertise while remaining open to unexpected or critical student perspectives.

3.3 Context of the study

This study was conducted within a single educational setting, where the CYOA-CBL framework was applied twice—once each year—over two consecutive academic years, with iterative refinements made after the first implementation. The study took place within a six-month, mandatory graduate-level course titled "Innovation and Entrepreneurship Studies", offered as part of a Master's program in Computer Science at the University of Trento, a mid-sized Italian university. This is a 6-ECTS mandatory curricular course designed for second-year Master's students in Computer Science (CS) who are following a curriculum that integrates CS with Innovation and Entrepreneurship. The course is delivered in English and represents the capstone module of a minor in Innovation & Entrepreneurship (I&E) embedded within the technical curriculum.

Since 2018, this course has adopted Challenge-Based Learning (CBL) as its core pedagogical framework, emphasizing interdisciplinary teamwork, problem-solving, and innovation. Students are divided into self-organized teams and assigned to address a real-world open problem proposed by an external actor (e.g., companies, public institutions, NGOs). During the course, teams must identify and address the challenge within the context of their assigned case, such as considering alternative business models for a technological startup or analyzing go-to-market scenarios for the launch of a digital product. Students are required to ground their reflections by exploring specific areas like the business environment, competition, suppliers, partners, environmental and sustainability issues, etc., using both deductive methods (i.e., through desk research) and inductive methods (i.e., through field work) as appropriate. This approach allows them to apply knowledge gained throughout their academic careers, particularly concepts related to the I&E minor and to real-world problems. The CYOA-CBL approach was implemented over the academic years 2023/2024 and 2024/2025 as an enhancement to the course's CBL structure. For these two iterations, the course combined in-class sessions, mentoring sessions with independent group work as foresee by the CYOA-CBL structure, described above and presented in a previous paper [25].

3.4 Participants and recruitment

The study involved Master's-level Computer Science (CS) students mandatory enrolled in the curricular course on Innovation and Entrepreneurship at the University of Trento described above. The total number of participants and team configurations varied across the two longitudinal iterations of the CYOA-CBL framework, as outlined in Table 1.

Table 1. Overview of study participants

Context	Academic Year	# Students	# Teams	Level	Participation type
Curricular Course – Iteration 1	2023/2024	51	12	Master's (CS)	Mandatory course
Curricular Course – Iteration 2	2024/2025	33	8	Master's (CS)	Mandatory course

While the course is structurally embedded within a technical CS curriculum, the student population is historically heterogeneous and highly multidisciplinary. The cohorts comprised students from double-degree programs that integrate

technical competencies with business skills, including the EIT Digital Master School[1], EIT Urban Mobility[2], and EIT Manufacturing Master Schools[3]. Consequently, alongside students from pure ICT tracks and international exchange programs, the participants possessed diverse academic backgrounds in fields such as Human-Computer Interaction and Design, Statistics, Mechanical Engineering, and Business. This unique cultural and disciplinary diversity makes the cohort an ideal testbed for evaluating an adaptive framework like CYOA-CBL, as students brought varied preferences and collaborative expectations to the project workflows.

While course enrollment was mandatory as part of the degree requirement, participation in the research study (filling out surveys and engaging in interviews) was voluntary. All students who completed the course were included in the study. Since the CYOA-CBL framework was adopted during the mandatory course, participation in the pedagogical activities was required as part of the course requirements. However, a clear distinction was maintained between the educational intervention and the research study. While the pedagogical model was compulsory, participation in the research with surveys and semi-structured interviews was voluntary. Participants were recruited through course enrollment and a comprehensive information regarding the study's objectives, data handling protocols, and consent procedures was provided to all participants prior to any data collection.

Due to structural and temporal constraints, it was unfeasible to conduct in-depth interviews with all the students of the course. Therefore, to ensure a balanced and informative representation of student experiences, a purposive maximum variation sampling strategy was employed for the interviews. Participants for the individual interviews were primarily selected based on two key indicators: their final course grade (as a proxy for academic performance) and field notes recorded by the teaching staff regarding real-time team dynamics, level of engagement, and collaborative friction. These two dimensions served as the main criteria for sampling, aimed at capturing a spectrum of experiences with the CYOA-CBL framework. Additional variables, such as gender, academic track, country of origin (Italy, EU, or non-EU), learning modality (online or in-person), and assigned mentor (M1 or M2), were considered as control variables to ensure heterogeneity and contextual depth across the sample. This approach supported an in-depth understanding of how different learner profiles interacted with and perceived the CYOA-CBL structure. Table 2 provides a detailed breakdown of the interview participants' profiles based on the selection criteria and the corresponding academic year, offering a transparent overview of the diversity across the two iterations of the study.

3.5 Data collection

This study adopted an iterative Mixed-Methods Action Research design, which can be conceptualized as a Concurrent Triangulation Design [9] across two consecutive editions of the mandatory curricular course described in Section 3.3. To gain a comprehensive understanding of the pedagogical framework and answer the research questions, we collected both closed-ended information (e.g., Likert-scale survey answers) to capture broad patterns in student satisfaction and process understanding, and open-ended information (e.g., semi-structured interviews, artifact observations, and open survey responses) to uncover the underlying dynamics and qualitative nuance of the students' experience.

The design consists of distinct phases, inspired by the approach used by Doulougeri et al. in a study on factors influencing students' experience with CBL [12]:

[1] https://masterschool.eitdigital.eu
[2] https://www.eiturbanmobility.eu
[3] https://www.eitmanufacturing.eu

Table 2. Overview of interview participants by demographic and academic year

Criteria	Variable	AY 2023/24	AY 2024/25
Gender	Male	5	4
	Female	4	6
Course Track	Autonomous Systems	0	1
	Data Science	3	4
	HCID	1	2
	Fintech	1	0
	Business	1	0
	Cybersecurity	2	3
	Information Engineering	1	0
Origin Country	Anonymous	4	3
	Other EU Students	4	3
	Non-EU Students	1	4
Grade	> 25/30	7	9
	≤ 25/30	2	1
Experience	In Presence	8	10
	Online	1	0
Mentor	Mentor 1	6	5
	Mentor 2	3	6

(1) an anonymous group-based phase survey delivered at the end of each phase of the course, providing a general understanding of students' comprehension of the process (named "phase survey") with both open and close-ended questions [12];
(2) an anonymous individual survey at the end of the course to gather general impressions on the course and validate the results that we had from the phase surveys (named "final survey") with both open and close-ended questions;
(3) in-depth semi-structured interviews to further refine and explain the results by delving into students' views in more depth [9, 12];
(4) observations from the teaching staff regarding the student teams dynamics.

Additionally, for the second iteration and in line with the action research principle we improve the data collection strategy and we replace the static path-tracking surveys used during the first iteration. Instead, we asked each team to use a Miro board [4] - a digital collaborative whiteboard platform - to get more precise evaluation of the path taken by each group of student. In the first iteration, we asked teams to "categorize" their path (e.g., *"we are doing a tech path"*). However, after the analysis of the results, we thought it was too abstract and we wanted to have a depth understanding of the teams "adventure". For this reason, for the second iteration, we designed for each team a custom "CYOA-CBL Board" on Miro. As shown in Figure 3, the board functions as a dynamic timeline divided into the six phases of the framework (from Challenge Identification to Solution Proposal). Instead of selecting a pre-defined label, teams were asked to populate the board with specific activities they performed during each phase. This digital workspace allows students to visually map their journey in real-time, making the abstract concept of "choosing a path" more tangible.

[4] https://miro.com/

The data collection procedures are described below, presented separately for the quantitative and qualitative phases in chronological order.

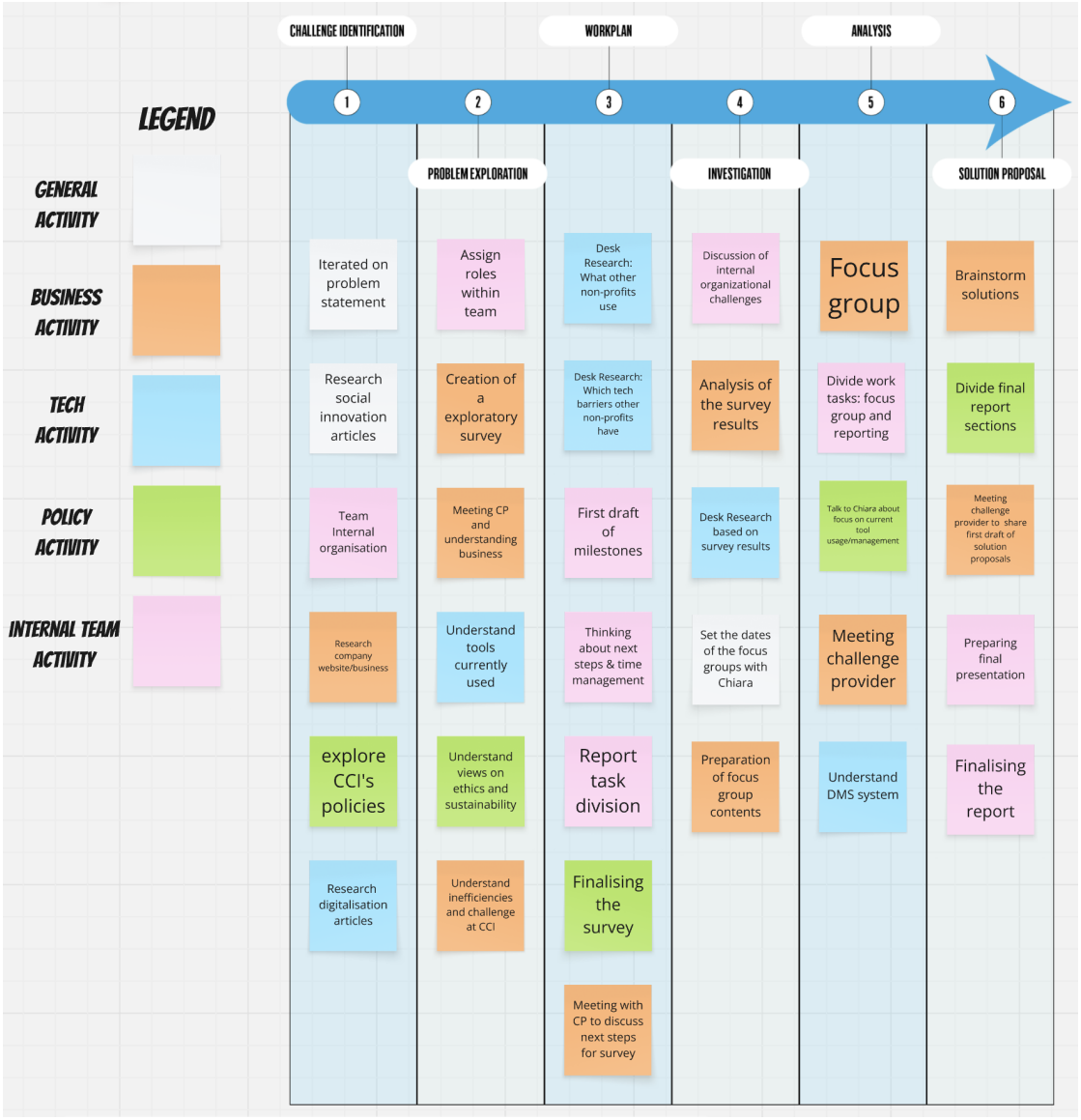


Fig. 3. The "CYOA-CBL Board" on Miro used in Iteration 2 by Team 1. The horizontal axis represents the course timeline (Phases 1-6), while the vertical arrangement and color coding represent the type of activity performed by the team.

3.5.1 Quantitative data collection. The quantitative data were collected through structured surveys provided via Google Forms. As described before, two types of surveys were employed: one distributed after each of the six phases of the CYOA-CBL process ("phase survey"), and one final survey conducted at the end of each course iteration ("final survey").

The logic of the phase surveys follows the approach of Chanin et al., who asked students to complete a survey at the end of each phase of their process to evaluate a framework for a CBL course [7]. The primary objective was to gather reflections on what students learned or struggled with, assess the effectiveness of tutorials and mentoring sessions, and determine which path students followed. The phase surveys were filled out collaboratively by each student team at the conclusion of every CYOA-CBL phase and it included closed-ended questions using a 5-point Likert scale.

The final survey was a standard, individual evaluation survey administered to all students at the end of the course to assess overall satisfaction and specific course components. It served to gather more comprehensive personal reflections on the overall learning experience. The survey consisted of closed questions on a 5-point Likert scale, similar to the previous one, ranging from strongly disagree to strongly agree

All surveys were completed anonymously to minimize potential bias and ensure that students could provide honest feedback without concern for academic consequences. Surveys were administered before final grades were released, and students were not identifiable by instructors.

3.5.2 Qualitative data collection. The qualitative phase consisted of teacher's observations, few open-ended prompts in the phase and final surveys, artifacts from the Miro board (only in the second iteration) and semi-structured interviews with a voluntary subset of students.

The short open-ended questions of the two surveys were designed based on a similar study presented by Detoni et al. [11] and adjusted to fit the context of this research. The open-ended questions in the phase survey used the following prompts:

- *In one word, what did you learn the most during this phase?*
- *In one word, what did you struggle the most with during this phase?*
- *In one word, what would you have done differently in the tutorial/mentoring for this phase?*

The open-ended questions in the final survey used the following prompts:

- *Please explain if and why how we conducted the course satisfied you*
- *Please explain what was the most problematic aspect of the course for you*
- *Please explain if you would propose this methodology again in the next year, and indicate strengths and weaknesses*

The semi-structured interviews, were crucial for the research design, helping to refine and explain the data gathered during the course. These interviews were organised after the evaluation process and exam to avoid conflicts of interest. Students did not receive any course credit or any incentive for consenting to data collection, and they did not have any penalty for declining to participate in the study.

Participants were encouraged to discuss their experiences with the course and the CYOA-CBL methodology overall. We asked about their challenges throughout the course, how they worked and structured their process and their thoughts on the various activities within the course. Each interview lasted approximately 30-45 minutes. Most of them were conducted online via video conferencing. Interviews were held in English, except when the participant was a native Italian speaker; in such cases, the conversation was held in Italian to ensure the students felt comfortable with their native language when possible. Interviews conducted in Italian were carefully translated by us without altering

Table 3. Implementation Matrix of Data Collection Sources across Iterations 1 and 2

Data source	Data format	Level & timing	Primary research aim	Sample size / extent
Phase surveys	Closed-ended (Likert) & short open-ended prompts	Team-level; administered at end of each of 6 phases	Evaluate phase-specific process understanding, mentoring efficacy, immediate struggles and path choices	Iteration 1: 12 teams × 6 phases = 72 responses Iteration 2: 8 teams × 6 phases = 48 responses *Total: 120 team responses*
Final survey	Closed-ended (Likert) & open-ended prompts	Individual-level; end of course	Assess overall course satisfaction, overall learning gains, and structural feedback	Iteration 1: 19 / 51 students (37.3%) Iteration 2: 16 / 33 students (48.5%) *Total: 35 individual responses*
Semi-structured interviews	Audio-recorded open-ended transcripts	Individual-level; post-grading period	Explain quantitative trends; explore deep student experiences, challenges, and path choices	Iteration 1: 9 participants Iteration 2: 10 participants *Total: 19 interviews (30–45 min, M = 37.2 min)*
Miro boards	Visual artifacts	Team-level; during the course period (Iteration 2)	Map real-time team path trajectory	Iteration 2: 8 visual team boards
Teachers notes	Qualitative field notes	Teacher-level; ongoing throughout course	Document classroom and teams dynamics	Ongoing observation across both iterations

meanings or phrases. Student interviews were conducted only after the end of the course, once grades had already been assigned and finalized. This timing was intended to reduce potential bias and ensure students felt free to speak openly.

3.5.3 Data collection totals. Across both course iterations, data collection yielded a total of 120 team-level phase survey responses, 35 individual final course evaluation survey responses, and 19 semi-structured participant interviews.

More specifically, a total of 120 team-level responses were collected across the two iterations of the curricular course. In Iteration 1, 12 teams completed surveys across 6 phases ($12 \times 6 = 72$ responses). In Iteration 2, 8 teams completed surveys across 6 phases ($8 \times 6 = 48$ responses).

The individual final evaluation survey yielded an overall response rate of 41.7% (35/84 students). In Iteration 1, 19 out of 51 enrolled students responded (37.3%), while in Iteration 2, 16 out of 33 enrolled students responded (48.5%).

A total of 19 individual interviews were conducted following the conclusion of the courses: 9 following Iteration 1 and 10 following Iteration 2. Interview durations ranged from 30 to 45 minutes.

Table 3 provides a comprehensive implementation matrix mapping the research aims, data sources, formats, collection timing, and participant sample sizes across both iterations.

3.6 Data-analytic strategies

Quantitative and qualitative data were collected concurrently during the course offerings and analyzed independently using method-appropriate techniques. The results were then integrated during the interpretation phase to cross-validate, corroborate, and triangulate findings across data sources.

3.6.1 Quantitative data analysis. Quantitative analysis was conducted to establish statistical patterns regarding student satisfaction, process understanding, team path choices, and perceived scaffolding utility across both course iterations.

Primary data collected from the phase surveys and the final surveys were aggregated and analyzed using descriptive statistical techniques. For the phase-by-phase Likert-scale items evaluating tutorial effectiveness, mentoring effectiveness, and next-step clarity, arithmetic means (M), standard deviations (SD), range bounds, and modal scores were computed. These metrics enabled tracking of central tendencies, group rating dispersion, and longitudinal satisfaction trajectories across the six phases of CYOA-CBL. Then, data regarding teams' path choices (only for iteration 1) were analyzed using stacked bar charts (see Chart 4). This visual representation enabled us to track the absolute frequency and distribution of student teams selecting specific paths (e.g., *Business modelling*, *Market analysis* .. across the sequential phases of the course (from phases 2 to 6). Finally, for the final survey, ordinal response data were summarized using percentages, modal choices, means and standard deviations to measure student engagement, structural clarity, and activity utility.

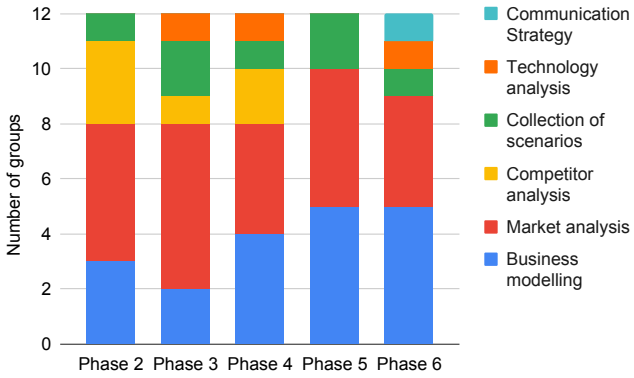


Fig. 4. Groups and paths.

3.6.2 Qualitative data analysis. For qualitative data, comprising open-ended survey entries, transcriptions of semi-structured interviews, instructor observation field notes, and visual artifacts from Miro boards, we performed an inductive Thematic Analysis adhering to the six-phase thematic framework of Braun and Clarke [5]. Audio recordings of the interviews were transcribed using Whisper executed locally to safeguard participant privacy and minimize data exfiltration risks. Subsequent qualitative coding was facilitated using NVivo Software (version 14).

As mentioned previously, we adopted a combined deductive and inductive coding strategy [5]. While initial coding was guided by theoretical concepts identified in the literature, we avoided forcing the data into a rigid predefined structure. Instead, additional codes and overarching themes were allowed to emerge organically from the data, including interview transcripts, open-ended survey prompts, instructor field notes, and Miro board artifacts. This hybrid approach allowed us to leverage domain expertise while ensuring that the analytical categories captured participants' lived experiences, unexpected decision patterns, and self-reported challenges.

3.6.3 Mixed methods analysis and data triangulation. In accordance with the Concurrent Triangulation Design, the quantitative and qualitative findings were integrated during the final synthesis phase to compare, contrast, and corroborate results.

Quantitative statistical trends were placed side-by-side with qualitative themes, direct quotes, and Miro board visual path tracking corresponding to the same phase or research question. This comparison served to determine where

qualitative student narratives converged with, expanded upon, or contradicted quantitative feedback, producing a multi-source evaluation of the CYOA-CBL methodology.

3.7 Methodological integrity

To establish the credibility and transferability of our findings, this study established criteria for methodological integrity in computing education and mixed-methods research [9**?**]. We implemented explicit strategies across four core dimensions of rigor: credibility, transparency, reflexivity, and transferability.

Data were collected across two distinct offerings of the course, encompassing 20 distinct student teams ($N = 84$ total enrolled students). This sample structure captured a rich diversity of team dynamics, academic backgrounds, and non-linear pathway choices across the CYOA-CBL framework.

Credibility was supported through data source triangulation and supplemental analytic checks. In accordance with our Concurrent Triangulation Design, claims were cross-validated across four distinct qualitative and quantitative data streams: individual Likert survey items, open-ended survey prompts, interview transcripts, and interactive Miro board visual tracking artifacts. Findings were only synthesized when corroborated across multiple sources. When discrepancies emerged between quantitative feedback and qualitative narratives, these divergent instances were explicitly analyzed rather than dismissed. To ensure findings remain transparently grounded in evidence, qualitative claims in Section 4 are accompanied by direct participant quotes, explicitly contextualized with the course iteration, and the interview question that elicited the response.

Because the primary researchers served the dual roles of course designers/instructors and data analysts, structured practices were embedded to mitigate researcher confirmation bias, power asymmetries, and social desirability effects. Qualitative analysis was conducted also inductively, allowing themes to emerge directly from participant accounts rather than forcing data only into pre-existing theoretical constructs or instructor expectations. However, we explicitly acknowledge that the analysis of the second course iteration was reflexively informed by the initial thematic analysis developed during the first iteration. Rather than treating the two cohorts as entirely isolated, the findings from the first iteration acted as a first lens during the analysis of the second cohort. To manage this analytical bias and remain open to novel phenomena, researchers actively looked for disconfirming evidence, contrasting dynamics, and newly emerging themes specific to the second iteration.

Student interviews were conducted only after the official conclusion of the course and the public posting of final grades. This timing explicitly separated participation from academic assessment, ensuring students could critique the CYOA-CBL model without fear of grade penalties.

All phase and final evaluation surveys were submitted anonymously via forms, preventing instructors from associating feedback with individual student identities during the active semester. Instructors maintained ongoing observational field notes during weekly mentoring sessions. These notes were used during thematic analysis to bracket personal assumptions and distinguish direct student observations from instructor interpretations.

To ensure transparency and to enable readers and educational practitioners to assess the transferability of our findings to other computer science curricula, we provide "thick descriptions" of the research setting. Section 3.3 explicitly details the pedagogical background, course structures, student population, and grading criteria, while Section 3.4 presents the demographic breakdown and 3.5 the implementation matrix.

4 Findings

4.1 Findings from iteration 1 (AY 2023/2024)

4.1.1 Quantitative findings. As described in Section 3.5.1, feedback was collected at the end of each process phase (phases 1 through 6) to evaluate student group perceptions across three core dimensions (see Table 4) using a 5-point Likert scale: tutorial effectiveness, mentoring effectiveness, and clarity of next steps. An analysis of the 72 responses from the first iteration shows that, overall, the mentoring sessions maintained high ratings throughout the intervention (M = 4.2 SD=0.2), reaching a peak average of M=4.4 (SD=0.7) during Phase 5. In contrast, tutorial effectiveness yielded an overall mean of 3.9 (SD=0.3), exhibiting greater initial variance and lower satisfaction in Phase 1 (M=3.5 SD=1) before stabilizing and peaking in Phase 2 and 5 (M=4.2 SD=0.4). The clarity of next steps averaged 4.2 (SD=0.3) across all phases, following a steady trajectory across the course progress.

The "clarity of the next steps" evaluations provide useful insights into student navigation within CBL environments. CBL literature suggests that the primary critical friction points occur during the initial stages, where students face substantial ambiguity regarding open-ended challenges [15]. In contrast, our phase data indicates high early clarity that experienced a minor dip during intermediate execution (Phases 2 and 4) before raising (M=4.4 SD=0.7) in the final stages. Throughout this trajectory, mentoring consistently received higher evaluations than tutorials, emphasizing the value of personalized, adaptive guidance during execution phases.

Table 4. Descriptive statistics across process phases (Mean ± SD) of 12 teams × 6 phases = 72 responses.

Phase	Tutorial effectiveness	Mentoring effectiveness	Clarity of next steps
Phase 1	3.5 ± 1	4.2 ± 0.7	4 ± 1.1
Phase 2	4.1 ± 0.4	3.9 ± 0.6	3.9 ± 0.8
Phase 3	3.7 ± 0.5	4.2 ± 0.9	4.2 ± 0.6
Phase 4	3.7 ± 0.7	3.9 ± 0.8	3.9 ± 0.7
Phase 5	4.2 ± 0.4	4.4 ± 0.7	4.5 ± 0.7
Phase 6	4 ± 0.7	4.3 ± 0.7	4.4 ± 0.7
Overall mean	**3.9 ± 0.3**	**4.2 ± 0.2**	**4.2 ± 0.3**

In each phase's survey, we asked students what path they were following and we summarised in Figure 4 the number of teams that chose a specific path during the various phases. By combining the responses of the teams for each phase, we have seen how some groups followed a clear linear process where they stuck with the same path (which we take as a proxy of the students following a structured approach), while others changed direction and paths more frequently (which we take as students opting for an open approach).

Three out of twelve teams adopted a structured approach, while the others opted for an open or in-between approach. For instance, Team 5 started its work with a business-oriented path but later changed direction to a technological analysis, whereas Team 11 started with a market analysis/scenario collection and concluded the project with a communication strategy. All in all, three teams never changed paths; six teams changed paths once; two teams changed paths twice, and one team changed paths three times. Notably, even the teams that changed paths multiple times never did so in two consecutive phases.

Table 5 and Table 6 reports the statistical distribution of student evaluations across some course dimensions and perceived activity effectiveness gathered through the "final survey". It provides a broader evaluation of the overall student experience on a 5-point scale. Responses were collected from N=19 out of 51 enrolled students. Given the

small sample size (N=19), each participant accounts for 5.26% ((1/19) * 100, i.e., +/- 0.05) of the total. Over 63% of respondents categorized mentoring sessions and meetings with the challenge provider as extremely helpful. High levels of satisfaction were also reported for the clarity of mentoring worksheets (68.4% "excellent") and direct engagement with teaching staff (73.7% "excellent"). Conversely, student ratings for tutorials were more widely distributed, with 26.4% of respondents indicating that tutorials were either "not at all helpful" or only "slightly helpful". This distribution aligns with the phase-level findings and highlights tutorial structure as a key area for enhancement in future course deployments.

Table 5. Statistical distribution of the students' evaluation of course dimensions (N = 19 out of 51)

Dimension	Poor	Fair	Okay	Good	Excellent	Mode
Level of engagement in course	1 (5.3%)	0 (0%)	6 (31.6%)	8 (42.1%)	4 (21.1%)	Good
Clarity of next steps	0 (0%)	1 (5.3%)	2 (10.5%)	3 (15.8%)	13 (68.4%)	Excellent
Clarity of general process	0 (0%)	2 (10.5%)	4 (21.1%)	4 (21.1%)	9 (47.4%)	Excellent
Engagement with teachers	0 (0%)	0 (0%)	3 (15.8%)	2 (10.5%)	14 (73.7%)	Excellent
Engagement with Challenge Provider	1 (5.3%)	0 (0%)	2 (10.5%)	4 (21.1%)	12 (63.2%)	Excellent
Teamwork with fellow students	0 (0%)	0 (0%)	3 (15.8%)	4 (21.1%)	12 (63.2%)	Excellent
Clarity of mentoring worksheets	0 (0%)	0 (0%)	0 (0%)	6 (31.6%)	13 (68.4%)	Excellent

Table 6. Statistical distribution of perceived activity effectiveness (N = 19 out of 51)

Activity	Not at all	Slightly	Somewhat	Very	Extremely	Mode
Tutorials	1 (5.3%)	4 (21.1%)	5 (26.3%)	4 (21.1%)	5 (26.3%)	Somewhat
Mentoring sessions	0 (0%)	1 (5.3%)	2 (10.5%)	4 (21.1%)	12 (63.2%)	Extremely helpful
Meetings with CP	0 (0%)	0 (0%)	2 (10.5%)	5 (26.3%)	12 (63.2%)	Extremely helpful

4.1.2 Qualitative findings. Qualitative findings for the first iteration were established through a thematic analysis triangulating semi-structured participant interviews (N=9), teacher observational notes, open-ended responses from the "phase surveys" (Phases 1–6), and the "final survey". This synthesis revealed three central themes regarding student experiences during the initial deployment: (1) team navigation of open versus structured paths, (2) the scaffolding, autonomy, and pacing afforded by the CYOA-CBL framework, and (3) a sharp divergence in the perceived utility of mentoring versus tutorials.

Structured or open approaches.

A central finding across participant accounts was the explicit recognition of team agency in selecting, maintaining, and adapting project pathways. Rather than enforcing a rigid methodology, the CYOA-CBL framework granted teams the freedom to align their process with their emerging project goals. While some groups maintained a consistent path, others adapted their approach as new information surfaced. For instance, Student 3 noted that their team "stuck to the same [path], but we had some variation towards the end when we found more relevant data." Similarly, Student 7 highlighted the contrast between traditional course expectations and the agency granted by the framework:

> "We stuck [to the same path] from the beginning [but] I was surprised by the fact that we didn't really have to do a business model during the course. [The course] was more open [...] we weren't expecting to have [the possibility of doing a marketing strategy]."

This sense of ownership was reinforced by Student 3, who emphasized that course execution was governed "more like what the expectations that we had as a team more than what the professor or the course had upon us". Furthermore, Student 1 explained how they changed path more than once during the process. In the beginning, the team narrowed down two options, and chose one of the two. However, after collecting some field data, the team understood it was not the right decision, and shifted to the other option and followed it until the end:

> "Let's say, perhaps our mistake was assuming that was the right way to go.".

Teacher observations and final deliverable reviews confirmed that teams on identical pathways personalized their analytical tools and final artifacts to suit their specific challenge needs. For example, when conducting market analysis, one team combined expert interviews with user surveys, while another relied primarily on desk research analyzing industry size and market dynamics. Students actively adapted deliverable structures rather than treating templates as rigid constraints. As Student 8 reflected:

> "Even in the final report, we indeed added sections and removed some that did not fit our work. So we always adapted, trying to follow the instructions well or poorly, but we adapted to our case."

Scaffolding, autonomy, and pacing.

The integration of real-world challenges fostered high student involvement and project ownership. Students reported that addressing real-world problems created a sense of "extra responsibility". Students noted that the predefined process structure of CYOA-CBL made open-ended challenges approachable, transforming what could have been a disorienting experience into a manageable, step-by-step workflow.

Open-ended challenges require higher creative effort [4] and it was appreciated by Student 4, who enjoyed "brainstorming and being a bit more creative instead of just studying from books". However, some students recognized that structural guardrails of CYOA-CBL prevented disorientation. Student 9 noted that "having the structure like that certainly helped a bit because you had the stakes marked, so you weren't too free to get lost who knows where". Student 8 summarized this balance as an optimal middle ground:

> "If we had been freer, there would have been the real risk of taking a direction very far from what you actually want, and the risk of digressing. But if it had been more detailed, they would have left us little space to do what we wanted. [The proposed structure] was a good compromise.".

One student wrote: "The main strength is the flexibility and dynamic nature of the course structure.". Someone else added: "The course was conducted in a structured way since the beginning; [however] it really felt like we own the course and there was a sense of extra responsibility.".

This scaffolding directly influenced project pacing and workload management. Bi-weekly mentoring sessions and structured phase worksheets established a continuous work rhythm that prevented end-of-semester delivery stress. Student 5 explained that bi-weekly progress updates forced the team to work "each and every week," contrasting this with traditional courses where work is back-loaded into the final weeks. Student 5 added: "I didn't feel that much pressure [...] because when you are working every week, and you have a work progress in line, then you don't feel too much pressure all of a sudden." Student 1 similarly noted that involved company mentors and self-paced progress allowed them to "delve into the challenge at our own pace throughout the whole process.".

However, one interview revealed a complementary challenge regarding long-term semester pacing. Despite the mentoring sessions, students noted difficulty sustaining internal motivation across a four-month project without formal intermediate checkpoints:

> "I think [...] the semester is quite long. I'm not used to, to work on a project for [so long time]. So [...] maybe like a midterm presentation, which is part of your grades [can] motivate [the group] to work on it in like halfway."

Analyzing open-ended questions revealed how student struggles evolved across project stages. Early phases (Phases 1–3) involved cognitive alignment hurdles, such as defining project scope and establishing team roles. Intermediate phases (Phases 4–5) presented severe operational bottlenecks in field research, including difficulties formulating survey instruments, recruiting participants, and obtaining specific market data. In Phase 6, challenges shifted toward synthesizing broad findings into a concise, prioritized solution. Adding to these internal hurdles, several groups faced friction from unresponsive Challenge Providers. While frustrating, this external ambiguity ultimately forced teams to exercise self-direction, construct contingency plans, and take full ownership of their project outcomes.

Divergent utility of mentoring versus tutorials

A prominent theme across all qualitative data streams was the contrast in how students evaluated instructional support activities. Bi-weekly mentoring sessions were praised as the most valuable component of the course. Students emphasized that individual group mentorship provided essential progress checks, validated strategic decisions, and offered clear actionable steps.

Conversely, perceptions of tutorials were deeply divided. For less structured or struggling teams, tutorial exercises provided a helpful collaborative space to advance project tasks. Student 6 appreciated in-class group activities and student 5 noted that "we had really good conversations during the tutorials... it's the best part of the course where we can share ideas,". However, for highly self-directed teams, tutorials were frequently perceived as redundant or misaligned with their pace. Student 8 criticized in-class exercises:

> "I didn't fully understand the point of working in class [during tutorials] because then we always did it again at home in a more thorough way. For our group, doing the in-class part wasn't particularly useful... For me, they should be more frontal lessons."

Student 9 similarly observed that because their group was ahead of schedule, tutorials felt repetitive. Interview data indicated that while a minority of students preferred retaining tutorials as structured co-working sessions, the majority recommended restructuring them to include more frontal theoretical lectures, advanced domain content, or challenge-tailored examples. As Student 4 observed, a key structural challenge was that "every group has their own challenge, their own work, and their own timeline," making generic tutorial content inherently difficult to calibrate across heterogeneous project teams.

4.2 Refining the framework: from iteration 1 to iteration 2

The initial deployment of the CYOA-CBL framework (Iteration 1, AY 2023/2024) provided a proof of concept that the tension between structured CBL courses and student autonomy can be mitigated by allowing teams to self-regulate their level of structure and CYOA-CBL can be one possibile solution. However, following the action research principles, the analysis of the first iteration highlighted specific friction points that required intervention.

While students validated the core philosophy of the framework, qualitative feedback exposed areas where the CYOA-CBL needed fine-tuning. Specifically, the tutorials were appreciated only partially, and the long duration of the project led to motivation drops in the middle of the semester. Furthermore, the mechanism for tracking the chosen "adventure" with surveys were not sufficient for capturing the nuance of student workflows.

Based on these findings, we developed CYOA-CBL Iteration 2 for AY 2024/2025, introducing three practical improvements: additional tutorial materials (including frontal lectures on key topics such as desk research and survey design, alongside guest speakers on challenge-relevant topics), a midterm presentation to sustain student engagement and provide timely feedback, and a visual tool to enhance data collection and track learning progress, as described in Section 3.

4.3 Findings from iteration 2 (AY 2024/2025)

4.3.1 Quantitative findings. Even for the second iteration, quantitative findings were derived from both the "phase surveys" administered across the six course phases and the "final survey".

Across the six phases (see Table 7), student groups evaluated clarity of next steps highest overall (M=4.1 SD=0.5), closely followed by mentoring effectiveness (M=4 SD=0.2), while tutorial effectiveness received lower and more variable ratings (M=3.7 SD=0.4). The data highlights that while procedural clarity steadily climbs from initial ambiguity to final project delivery, mentorship acts as a crucial continuous anchor, particularly during initial problem framing and midpoint execution.

Table 7. Descriptive statistics across process phases, second iteration (Mean ± SD) of 8 teams × 6 phases = 48 responses.

Phase	Tutorial effectiveness	Mentoring effectiveness	Clarity of next steps
Phase 1	3 ± 1.1	4.2 ± 0.7	3.3 ± 1.4
Phase 2	4 ± 0.9	4 ± 0.8	4.1 ± 1.1
Phase 3	3.9 ± 0.8	4 ± 0.8	3.9 ± 1.3
Phase 4	3.9 ± 0.6	4.3 ± 0.9	3.9 ± 1.1
Phase 5	3.5 ± 1.2	3.9 ± 1	4.5 ± 0.8
Phase 6	3.9 ± 0.8	3.8 ± 1	4.6 ± 0.7
Overall mean	**3.7 ± 0.4**	**4 ± 0.2**	**4.1 ± 0.5**

Table 8 and Table 9 reports the statistical distribution of student evaluations in the final individual course survey (N=16 out of 33 enrolled students). Given the small sample size (N=16), each participant accounts for 6.25% ((1/16) * 100, i.e., +/- 0.06 of the total) in this second iteration. It shows that direct engagement with teaching staff is the highest-rated dimension, with 50.0% of respondents reporting excellent engagement. Students also confirmed a strong structural understanding of the course, reporting high clarity regarding the general process and next steps. The structured guidance provided by mentoring worksheets was similarly validated, showing remarkable cross-student consensus.

In terms of activity effectiveness, mentoring sessions were rated consistently high, with 87.5% of respondents categorizing them as either "very" or "extremely helpful". Tutorials were rated more moderately, with a predominant mode of "somewhat helpful" (43.75%), reinforcing the phase-level finding that tutorial content represents a primary aspect for refinement. General CP engagement yielded the highest dispersion among all measured dimensions (SD=1.7), spanning ratings from Poor (25.0%) to Excellent (43.75%). This variance translated directly into perceived meeting effectiveness with CPs, showing how heterogeneous levels of external stakeholder availability and commitment can impact a core structural pillar of the CBL course experience.

4.3.2 Qualitative findings. Qualitative findings for the second iteration were established through a hybrid thematic analysis combining an initial deductive baseline from Iteration 1 with an inductive analysis of participant interview transcripts, open-ended responses from bi-weekly phase surveys (Phases 1–6), open-ended responses from the final

Table 8. Statistical distribution of the students' evaluation of course dimensions (N = 16 out of 33), second iteration

Dimension	Poor	Fair	Okay	Good	Excellent	Mode
Level of engagement in course	1 (6.25%)	0 (0%)	1 (6.25%)	9 (56.25%)	5 (31.25%)	Good
Clarity of next steps	0 (0%)	1 (6.25%)	1 (6.25%)	7 (43.75%)	7 (43.75%)	Good / Excellent
Clarity of general process	0 (0%)	0 (0%)	2 (12.5%)	9 (56.25%)	5 (31.25%)	Good
Engagement with teachers	0 (0%)	0 (0%)	1 (6.25%)	7 (43.75%)	8 (50.0%)	Excellent
Engagement with Challenge Provider	4 (25.0%)	2 (12.5%)	2 (12.5%)	1 (6.25%)	7 (43.75%)	Excellent
Teamwork with fellow students	0 (0%)	0 (0%)	5 (31.25%)	6 (37.5%)	5 (31.25%)	Good
Clarity of mentoring worksheets	0 (0%)	0 (0%)	3 (18.75%)	9 (56.25%)	4 (25.0%)	Good

Table 9. Statistical distribution of the students' perceived activity effectiveness (N = 16 out of 33), second iteration

Activity	Not at all	Slightly	Somewhat	Very	Extremely	Mode
Tutorials	0 (0%)	2 (12.5%)	7 (43.75%)	6 (37.5%)	1 (6.25%)	Somewhat helpful
Mentoring sessions	0 (0%)	0 (0%)	2 (12.5%)	9 (56.25%)	5 (31.25%)	Very helpful
Meetings with CP	1 (6.25%)	3 (18.75%)	4 (25.0%)	2 (12.5%)	6 (37.5%)	Extremely helpful

survey, and Miro process artifacts. This triangulation revealed three central thematic areas: (1) the transition from a binary "Structured vs. Open" framing to a multidimensional path matrix, (2) student perceptions of the CYOA-CBL framework regarding adaptive learning, autonomy, and structural tension, and (3) student evaluations of specific instructional tools, learning activities, and operational bottlenecks during the course period.

From "Structured vs. Open" to a Multidimensional Path Matrix

Analysis of Miro boards revealed that while five out of eight teams maintained a consistent primary pathway throughout the semester, three teams exhibited significant domain shifts.

Visual mapping demonstrated that the traditional binary categorization of "Structured versus Open" CBL [4] was insufficient to describe student navigation. Notably, no similar figure existed in the first iteration; in this cycle, richer and more detailed data was collected through the use of Miro and a phase-by-phase analysis of each student group's activities. Consequently, teams distribute themselves across two spectra defined by two distinct axes, forming a four-quadrant matrix that categorizes team behaviors (see Figure 5). The matrix is defined by two intersecting axes representing continuous spectra:

Process trajectory (from linear to dynamic): this axis describes the directional stability of the team. On one end, **Linear** teams follow the phases sequentially without major deviations. On the other, **Dynamic** teams show high adaptability, iterating on previous phases or radically changing their project direction (e.g., from Tech to Policy) in response to friction or new insights.

Activity scope (from specialized to integrative): this axis describes the breadth of disciplinary integration within a single phase. **Specialized** teams focus deeply on a single domain (e.g., addressing only the technological aspects of the challenge). Conversely, the **integrative** end captures teams that combine multiple perspectives (Business, Policy, Tech). Since the course design does not prescribe a specific mode of integration, this category encompasses a spectrum of complexity [47]:

- Multidisciplinary: drawing on knowledge from different disciplines but keeping them distinct;
- Interdisciplinary: analyzing, synthesizing, and harmonizing links between disciplines into a coordinated and coherent whole;

These axes represent a continuum. While teams may drift towards the center or fluctuate during the semester, the intersection of the axes creates four archetypical behaviors that help explain the different "adventures" experienced by the students:

- Linear-integrative: teams in this quadrant maintain a steady forward progression but ensure every phase is analyzed through multiple lenses.
- Dynamic-specialized: teams in this quadrant tend to dive deep into a specific domain but are forced to change course radically when they encounter constraints.
- Linear-specialized: these teams choose a specific domain and follow the phases sequentially without major deviations. While efficient, this approach may sometimes reflect a "survival mode", where teams minimize ambiguity and exploration simply to meet the course requirements without exploring the open-ended challenges proposed by the course.
- Dynamic-integrative: this represents the most complex archetype. These teams constantly iterate on their process while simultaneously juggling many dimensions of the challenge. While this approach fosters deep learning and adaptability, it can feel chaotic and requires high team maturity to manage without losing focus.

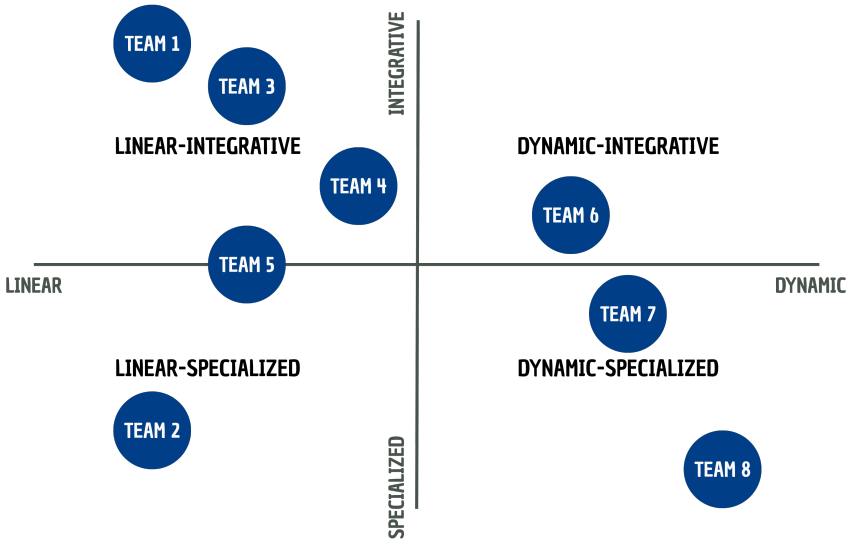


Fig. 5. Two-dimensional spectrum showing student team process flows and scope approaches.

This matrix moves beyond evaluating whether teams were more "structured" or "open", illustrating instead how students leveraged their freedom. Team 1, for instance, exhibited a *Linear-Integrative* pattern; their Miro board showed steady phase progression where every stage combined business and policy dimensions. As Student 1 explained:

> "It was a bit of a hybrid, between business and maybe policy too[...] when we made the proposal for the solution, we proposed solutions that were more technological but also just policy-based [...] the whole process ran in parallel."

In contrast, Team 8 represents a high degree of Dynamism and Specialized. Their journey was characterized by a distinct shift in domain. They started with a Specialized Tech focus but shifted completely to a Policy focus. Student 5 from Team 8 noted:

> "At the beginning, we thought we would focus heavily on the technological path because we preferred working directly with the software used by the company. In the end, this didn't turn out to be the case, so let's say the path shifted more towards a policy part. So from that point of view, it completely changed.".

Perceptions of CYOA-CBL: adaptive learning, autonomy, and structural tension

The CYOA-CBL framework's flexibility remained a highly valued component of the course design. It was broadly recognized as a primary driver of student agency, professional confidence, and reduced performance stress. Working directly on real-world business challenges fostered strong ownership. Student 7 noted that "flexibility was one of the best aspects... it reduced pressure and encouraged exploration", while Student 10 emphasized that the general structure of CYOA-CBL allowed them to "go to whichever direction we wanted". Student 5 explicitly connected this autonomy to professional self-efficacy:

> "In my opinion, it was more complicated than a guided challenge, but at least [...] this freedom made us feel more independent, more confident in our choices, because we also felt important to the company.".

Students strongly commended the framework's capacity to support self-directed learning paths, noting that autonomy in communicating with external companies and structuring team workflows cultivated independence and project ownership. The six-phases approach proposed by CYOA-CBL was praised for providing a clear, practical rhythm that made open-ended challenges approachable.

This adaptive capacity extended to final deliverables, where groups personalized report structures to match their challenge's specific needs rather than adhering to rigid templates. As Student 8 observed, being able to modify chapters of the final deliverable of the course allowed the team to be "free to adapt" based on challenge provider needs.

However, qualitative accounts also highlighted intra-team divergences regarding the optimal balance between guidance and autonomy. This divergence was shown within Team 1, where two members held opposing views on the structured phases. Student 2 perceived the phase requirements as an artificial constraint on real-world problem-solving:

> "There was this gap between [...] this real world problem [...] and then on the other side we had to do this step and this step [...] which not necessarily fit to the problem... to have more flexibility in this regard I think would be helpful to not have this structure."

In contrast, Student 1 viewed the exact same structural phases as a necessary safeguard: "There was a lot of freedom. [With more freedom] there would have been total anarchy.".

This divergence suggests that CBL can be perceived in different ways and the CYOA-CBL framework is aligned to the flexible characteristic that we were looking for.

Analyzing open-ended phase surveys revealed how operational friction shifted across the project lifecycle. During phases 1–3 teams struggled to align team members, establish clear workplans, and resist the temptation to jump prematurely to solutions before fully exploring the problem space. In phases 4–5 groups encountered substantial difficulties recruiting interview participants, distributing questionnaires, and securing responses. In Phase 5, delayed data collection directly impeded business modeling and synthesis, forcing teams to execute pivot strategies or construct

contingency plans. Finally in phase 6 the challenges centered on filtering extensive research data down to a prioritized, viable solution and rehearsing final pitch presentations under time constraints.

Evaluation of instructional tools, learning activities, and operational bottlenecks

Evaluations of specific instructional components revealed clear distinctions in utility across mentoring sessions, tutorials, and tracking tools:

Mentoring vs. Tutorials: mentoring sessions remained the most highly valued scaffold, providing actionable feedback, progress checks, and direction during periods of ambiguity. Mentoring was recognised as the critical scaffold sustaining students autonomy; students emphasized that clear worksheets and actionable, constructive feedback during mentorship provided valuable direction whenever groups experienced disorientation or internal disagreement. Conversely, tutorials exhibited diminishing utility as the semester progressed. While initial sessions effectively framed upcoming phases, later tutorials felt repetitive or disconnected from heterogenous group-work timelines. Some participants noted tutorials acted as a useful "trigger" for next steps or provided clear reporting outlines (Student 7, Student 10), but advanced teams felt forced to repeat work already completed independently. Participants recommended restructuring tutorials to be more dynamic, optional, or tightly integrated into mentoring hours.

Miro as a process tracker: while Miro boards proved valuable for research mapping, student feedback was mixed. Student 1 acknowledged the visual utility ("we could see our next comes this phase"), but noted that logging activities felt like an external administrative activity separate from daily workflows. The tool was perceived as an external administrative task, suggesting a need for better integration into the daily process.

Midterm presentation: introduced in Iteration 2 to address the long-semester pacing gap identified in Iteration 1, the midterm presentation was seen as a formal milestone. Although it introduced performance pressure, students recognized it as a necessary alignment point. Student 6 remarked:

> "I think that was the best part to get feedback early. We didn't really know what we were doing yet, and the feedback helped us realign."

Additionally, peer presentations enabled cross-team benchmarking, allowing groups to compare their work with one another and learn from collective feedback (Student 2).

Challenge provider: throughout all project stages, passive or unresponsive challenge providers represented a primary external bottleneck. Communication delays from CPs caused initial disorientation and forced teams to lag behind scheduled milestones. However, instructional intervention and peer support encouraged teams to take control of their own challenge direction, turning stakeholder friction into a practical exercise in self-management and adaptive problem-solving.

5 Discussion

This study evaluated the implementation of the Choose Your Own Adventure - Challenge-Based Learning (CYOA-CBL) framework across two iterations of a graduate-level and mandatory curricular course in Innovation and Entrepreneurship for Computer Science students. By combining quantitative tracking data (phase and final surveys) with qualitative insights (semi-structured interviews, students artifact analysis, and observational notes), this research explored how an adaptive scaffolding structure can address some of the current challenges with the development of CBL courses in computing education.

5.1 Cross-iteration and triangulation of mixed methods data

Despite the relatively small sample size, descriptive survey results indicated consistently positive evaluations across all measured dimensions. However, the findings should be interpreted cautiously and should not be considered statistically significant without further inferential analysis. Across both cohorts, mentoring sessions were rated as the most effective scaffold (Iteration 1: M=4.2, SD=0.2; Iteration 2: M=4.0, SD=0.2), with over 80% of students in final individual survey rating them as "very" or "extremely helpful". Qualitative feedback revealed that mentoring enabled teams to: 1) verify project direction and pivot when necessary; 2) strategically plan actionable next steps rather than merely review past work; and 3) being efficient thanks to real-time feedback that allowed teams not to get stuck and to move forward in the process.

Conversely, tutorials yielded lower and more dispersed satisfaction scores (Iteration 1: M=3.9,SD=0.3 and Iteration 2: M=3.7,SD=0.4). Triangulation with qualitative data explained this divergence and suggests that the CYOA-CBL framework addresses the "heterogeneity problem" of our mandatory engineering course. We observed a clear dichotomy in student needs: students with lower motivation or higher disorientation regarding open-ended problems relied heavily on the provided structure and pre-defined activities, while other teams used the framework's flexibility to deviate from the standard structure. While highly autonomous teams found generic tutorial exercises redundant with their independent work, less-motivated or struggling teams leveraged tutorials as essential co-working spaces to advance their project tasks.

In both iterations, student perceptions of "clarity of next steps" had a good evaluation (Iteration 1: M=4.2, SD=0.3 Iteration 2: M=4.1, SD=0.5). Rather than experiencing peak disorientation at the start, as commonly reported in standard CBL literature, students maintained high initial clarity, experienced a moderate dip during intermediate execution phases (Phases 2–4, where teams faced field research bottlenecks, survey recruitment challenges, and external stakeholder ambiguity), and reached peak clarity during final solution phase of the course.

Granular artifact tracking via Miro boards in Iteration 2 provided a key insight into team dynamics. Rather than a simplistic "Structured vs. Open" dichotomy, student path can be defined by a two-dimensional matrix defined by Process Trajectory (Linear vs. Dynamic) and Activity Scope (Specialized vs. Integrative). This taxonomy demonstrates that performance is not tied to a single ideal path: linear-specialized teams operated with high efficiency, while dynamic-integrative teams successfully managed broad perspectives, provided their dynamic pivots remained structured.

5.2 Final evaluations

RQ1: Is it possible to design a CBL course in computing education that is not disorienting for students who need more guidance, but still flexible for those who want to explore open-ended challenges?

The CYOA-CBL methodology demonstrates that structure and openness are not mutually exclusive, but can coexist within a unified course architecture. The six-phase structure and standardized mentoring worksheets provided "guardrails" that prevented disorientation. Students explicitly noted that having predefined phases reduced cognitive paralysis and performance anxiety without constraining their creative choices. At the same time, the framework granted teams complete agency over their analytical depth, methodology, and scope. Highly autonomous teams expanded section and course requirements, integrated primary field data, and pursued personalized trajectories without instructor overhead, proving that adaptive scaffold effectively support students needing guidance while providing open space for ambitious exploration.

RQ2: Can the CYOA-CBL format serve as an effective response to the need for adaptive learning pathways in challenge-based environments?

The CYOA-CBL framework offers an effective scaffold for self-regulated and adaptive learning. Data from both iterations showed that teams naturally adopted non-linear pathways without requiring direct instructor intervention. In Iteration 1, 9 out of 12 teams dynamically adapted their path at least once during the semester.

In Iteration 2, teams distributed themselves across four distinct archetypes (Linear-Integrative, Dynamic-Specialized, Linear-Specialized, and Dynamic-Integrative), dynamically pivoting (e.g., shifting from a technological focus to a policy-oriented strategy) based on their preferences, attitudes, motivations and challenges. The CYOA-CBL structure thus serves as a flexible "container" that organically absorbs real-world challenge ambiguity and deal with different type of students in a normal mandatory and curricular course of Computer Science students.

We observed how students could define their own experiences and processes, personalizing their course and approaching challenges from angles closer to their interests. Students stated that CYOA-CBL provided them with the freedom to be creative while maintaining a structure to avoid losing direction and becoming overwhelmed by the complexity of the challenges. Through these studies, we received a hint on how CYOA-CBL may foster an empowering learning environment, offering appropriate teaching and support processes where individuals can personalize their experiences to match their needs and objectives.

RQ3: How is the CYOA-CBL model perceived and interpreted by students with different dispositions toward learning, structure, and autonomy?

Student perceptions of the CYOA-CBL framework were deeply mediated by their individual and collective dispositions toward autonomy, intrinsic/extrinsic motivation, and tolerance for ambiguity. Qualitative data shows that learners saw CYOA-CBL as an empowering framework. They valued the freedom to communicate directly with external stakeholders, tailor final deliverables, and select challenge paths, explicitly linking this autonomy to increased professional confidence and self-efficacy. For students more inclined to traditional learning, the framework's structured worksheets, bi-weekly mentoring, and predefined phase goals served as vital safety nets. These elements allowed these students to maintain steady progress without feeling overwhelmed by the open-ended nature of real-world challenges. Qualitative evidence showed that even within the same team, members interpreted the exact same structural phases differently - one viewing them as a "guided freedom" against "total anarchy", and another as a mild constraint on real-world problem solving. This confirms that CYOA-CBL can operate as an adaptive environment capable of catering to contrasting student dispositions simultaneously.

5.3 Conclusions and future works

The findings of this two-year study offer some insights for educators implementing Challenge-Based Learning in computing and engineering curricula.

First, course design should prioritize flexible team mentoring over traditional frontal lectures. Tutorials should not be viewed as mandatory instruction for all, but as access points to the "minimum viable competency". Future iterations should consider treating specific tutorials as optional resources for getting the basics and being on track and offering "advanced tracks" for teams that have already mastered the basics.

Second, qualitative observations highlighted a pronounced divide in student mindsets. While intrinsically motivated students embraced open-endedness as an empowering opportunity, students viewing the compulsory course purely as a bureaucratic requirement exhibited high ambiguity aversion and passive engagement. This analysis is based solely on interviews and our observations of team dynamics, rather than on formal assessments.

There is a strong "fear of ambiguity" among some students, particularly those from technical backgrounds who lacked the mental models for self-direction.

We observed a "surface attitude" in students who treated the course purely as a bureaucratic requirement. Since the course was compulsory, they entered with a passive mindset. This was confirmed by low pre-course information seeking and acceptance of the course as a requirement rather than a choice. Students said: *"The course was mandatory... So I had to take it"*. Similarly, another said: *"I didn't choose it... it was automatic"*.

This attitude tend to see the course as a task to be completed, minimizing impact on personal time outside the classroom. Some students want to do *"everything in class and after that we are free"*.

This contrasts sharply with students possessing a "growth" attitude, such as an Erasmus student who had the opportunity to voluntarily choose the course, describing it as a *"fun challenge"*.

This exploratory study highlighted significant differences among student cohorts in a mandatory Computer Science course, revealing distinct attitudes, motivations, preferences, and learning approaches. These insights can help the computing education community better understand students and inform tailored support strategies. Future research will continue the investigation about the correlation between intrinsic/extrinsic motivation and student choices throughout the courses.

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TBD

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Appendix G

Semi-structured interviews guide

General experience

- How was you experience with I&E Studies?
- What were the most challenging things/aspects during the course? Why?
- How did you approach them?

Teams dynamics

- How would you describe the level (QUANTITY/QUALITY) of interaction and collaboration among your team members during the course?

Positive and negative factors of the course

- What were the aspects that facilitated your experience during the semester? What were the barriers or factors that hindered your experience?

Flexibility and CYOA-CBL structure

- Let's go back before the course began. Did you read the course title or hear about it from other students?
- What were your expectations?
- Was it really as expected or different?

- How did you structure your work during the course?
- How and what did you decide to do week by week?
- What was the least clear moment throughout the whole process?
- When was the first time you felt the pressure to create a final product to deliver?
- And from that moment until the final delivery, how did you feel?
- When you read the challenge assigned to you, did you expect something specific from your work? Did it seem reasonable to stick with it?
- Did you change your mind during the process?
- Did you realize you could change?

Educational tools and activities

- Was there a moment during the course when you felt the need for an explanation on a certain topic?
- Do you think the tutorial could have helped you?
- What do you think about the tutorials?
- How many tutorials did you attend in person?
- How did you use the tutorials in your process?
- What would you change about them?
- What do you think about the mentoring?
- Has it always been clear to you what to present during the mentoring sessions?
- Do you think all the mentoring sessions were necessary?
- What is the most useful aspect of mentoring sessions?
- What would you change about them? What did you appreciate?
- What suggestions or recommendations would you offer for improving the learning experience for future students and editions of the course?

Additional question for the second iteration

- What do you think about the Miro Board?
- Was it clear how to use it?
- What do you think about the mid-term presentation?