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Challenge-Based Learning and Constructive Alignment: A Challenge for Information Systems' Educators

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ABSTRACT

Challenge-Based Learning (CBL) is an emerging approach to the design of education activities known for its benefits in fostering student engagement and, consequently, positively affecting their learning outcomes. For the educator, the '*challenge in the challenge*' is to guarantee that the CBL-based education design follows certain regulations, like ensuring proper curriculum coverage with Constructive Alignment. This challenge becomes particularly difficult to address in the field of Information Systems, within Computer Science, where multiple practices can be followed to solve the same problem. This is even more challenging when CBL is applied at course-level, where the curriculum of the course focuses on a subset of those practices. This paper targets two central questions for the educators willing to apply CBL while complying with Constructive Alignment in their course design: (1) How to ensure that the results based on solutions designed to address student-defined challenges are successfully aligned to the course's intended learning outcomes? (2) How to use these results as evidence of learning and as an assessment component? We discuss our experience and lessons learned applying CBL for the redesign and execution of the Smart Industry Systems course of the University of Twente, while ensuring proper curriculum coverage and compliance with Constructive Alignment.

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1 INTRODUCTION

The University of Twente's (UT) mission is to empower society with sustainable solutions in order to put people first (UT 2023). UT seeks to achieve excellence in connecting people and technology by fusing technical and social sciences in various domains: enhancing health care through personalized technologies, developing intelligent manufacturing systems, reshaping our world with smart materials, engineering our digital society, and engineering for a resilient world. Consequently, UT is concerned with educating students effectively through courses that equip them to face challenges in various fields.

The Smart Industry Systems (SIS) master course is offered in the Business Information Technology Master (M-BIT) programme, as a mandatory part of the learning path for all students. The course is also offered as elective to other programmes, and it is particularly popular amongst Computer Science students. SIS has been offered for three years now, and students have ranked it as the best course in their programme in various categories, e.g., course content relevant to the educational program, clear and related learning goals. To further connect people and technology, align with UT's mission and vision, and provide students with the opportunity to participate in and control their learning, in 2022 we decided to apply the Challenge-Based Learning (CBL) approach in the SIS course.

CBL is an educational framework designed to support students (learners) to learn by means of an iterative life cycle of three phases (Nichols and Cator 2008)(Nichols et al. 2016). CBL drives learners through real-life challenges, and a multidisciplinary team supports the learners, including the challenge provider, lecturers, student assistants and a CBL mentor. Skills developed with CBL can increase the impact that learners have on society during and after their studies (Johnson et al. 2009). The CBL life-cycle covers three phases: (1) Engage, where learners move from an abstract big idea to a concrete and actionable challenge; (2) Investigate, where learners conduct research for actionable and sustainable solutions; and (3) Act, where evidence-based solutions are developed and the results are evaluated.

Studies have shown that students in higher education settings working within the CBL framework can boost their skills (e.g., leadership, autonomy, and critical thinking), maximizing their learning experience (Johnson et al. 2009), (Doulougeri et al. 2022b), (Martin, Rivale, and Diller 2007). Recent literature has shown that CBL can be particularly efficient for the topic of smart applications, e.g., in the case of 'smart campus' challenges (Zaballos et al. 2020). Therefore, the SIS was a suitable candidate for applying CBL, so students could benefit from this framework. This study discusses the effectiveness of implementing the CBL framework in the SIS course.

However, applying CBL in a course based on Constructive Alignment (CA) is challenging for the educator to guarantee certain educational constraints, such as proper curriculum coverage. This challenge is even harder in CS courses, where multiple practices can solve the same problem. This paper targets two central questions for the educators willing to apply CBL while complying with Constructive

Alignment in their CS course design:

- RQ1. How to avoid misalignment between the course's intended learning outcomes (goals) and the learning opportunities generated by student-defined challenges (teaching and learning materials)?
- RQ2. How to ensure that student-developed solutions provide evidence of learning (assessment) aligned with the course's intended learning outcomes (goals)?

This paper reports on a case study in which we address these questions and discuss the results, which are based on a comparison between the editions of the SIS course with and without applying CBL. The remainder of this paper is organized as follows. Section 2 presents the case study. Section 3 presents our findings and discusses them. Section 4 concludes and suggests topics for future research.

2 CASE STUDY: APPLYING CBL IN THE SMART INDUSTRY SYSTEMS COURSE

In this case study we compared the original SIS course given in 2021 as a "pure" project-based course, without applying CBL, with the 2022 edition in which CBL was applied. One of the motivators to use the SIS course is that recent research has demonstrated that CBL is particularly useful for the study of smart applications engineering, and entrepreneurship (Doulougeri et al. 2022b), (Doulougeri et al. 2022a), (Couch and Towne 2018), (Colombelli et al. 2022), (Gaskins et al. 2015).

2.1 Original Smart Industry Systems Master Course

In 2020, M-BIT and M-TCS master's students took the first project-based SIS course. The SIS course addresses business interoperability concerns in an integrated network of automation devices, services, and enterprise systems in the industry ecosystem, covering the full production process and multiple enterprise sectors. Real-world interoperability project assignments make the course multidisciplinary. In SIS' original course design, students spent half the time on lectures and related assignments and the other half on developing one of the predefined projects available. The projects' descriptions include the research context and some problems/research questions to be investigated, similar to what is described in (Bacon, Stewart, and Silver 1999) and (Bacon 2005). The bottom line here is that students worked on predefined research questions on projects drawn based on real-world projects (specifically inspired by one of the region's companies). Although the connection with reality is present, it's unclear how much of this connection is perceived by the students. Additionally, since the course lasts only ten weeks, we saw the predefinition of problems/tasks as an efficiency measure - since it helped avoid students using time for the precise definition of the investigation to be conducted.

2.2 The adaptation to CBL: working with ill-defined problems

Since 2021, the BIT programme management has motivated lecturers to offer students ”ill-defined” problems. The goal is to give students the opportunity of developing critical thinking and continuously develop the ’researcher approach’. Therefore, the ’efficiency measure’ we took in the previous design became inconvenient for the achievement of these new intended learning outcomes. Additionally, since CBL is inherently designed to guide students in the investigation of ill-defined problems (they usually define the challenge themselves), and also because CBL is known for increasing students’ engagement, we decided to update the SIS course from a typical PBL (Project-Based Learning) approach to a ’feasible’ CBL approach.

Our ’feasible’ CBL approach requires the entire learning cycle to take less than ten weeks. Leveraging on the fact CBL is a framework and not a method (Nichols et al. 2016), and its application has been continuously adapted by the founders themselves (Binder et al. 2017), we adapted our CBL approach to give students a written description of the research context, which is always the case of a local company. Since the issue is unclear, students were given multiple weekly times to discuss with company officials. These weekly time-sensitive exercises and milestones were meant to assist students stay on schedule. We predefined the ”Big Idea” and provided a context description for students to gather throughout the ”domain investigation phase” of CBL. Therefore, students had to investigate which challenges are more relevant to the companies and discuss (within the group) which ones engage them the most. Some differences from the original design are: (a) the connection with companies is now explicit, including weekly contact hours with company representatives, (b) the problems are no longer predefined, and (c) students use the CBL structured questioning schema to guide their investigation process (learning ”how to investigate,” i.e., the researcher approach). Additionally, to prevent disconnection of the chosen challenge with the ’teaching and learning materials’ and ’assessment’, each case had a set of constraints to ensure the chosen challenge (learning material) and the chosen solution (assessment material) are clearly connected to the course’s intended learning outcomes. Therefore, our approach differential is to steer students’ learning experience more than the classical CBL application. Consequently, in our approach, students have less freedom to choose their challenges and the solution to be developed.

When adapting the PBL to a CBL approach, the evaluation becomes more challenging. This is because students may define/identify challenges beyond the course material, which might result in having challenges not covering the course’s intended learning objectives (ILOs) (Nichols and Cator 2008), (Martin, Rivale, and Diller 2007), (Johnson et al. 2009). With CBL, students elaborate Guiding Questions (GQ) that help them learn by ’inquiry’. At this point, we offered students a team of CBL Mentors (lecturers) to help them in their journey. The mentors helped students in assessing whether their set of GQs covered all the knowledge they had to acquire and also whether the knowledge to be acquired is connected to the ILOs.

2.3 CBL Mentors: additional contact-hours for increased educational support

The new pedagogical design included the addition of lecturers (called ’CBL mentors’) to support students in the definition of the challenge (engage phase) and the learning activities (investigation phase). This measure helped to ensure the Constructive Alignment. Furthermore, the mentors worked as a bridge, connecting students to challenge providers and moderating this relationship.

3 RESULT ANALYSIS & DISCUSSION

The analysis of the results pointed to two directions: the need of mentors and the need of adapting the CBL phases to assure Constructive Alignment. Here we also describe the perceived quality of the course, and discuss the research findings.

3.1 The need for mentors

Although we provided students with a research context description and a structured schedule of contact-hours with companies representatives, we found it still relevant the risk of disconnection between learning materials (represented by the CBL Investigate Phase and its Guiding Questions), assessment (The solution developed and its report), and the courses ILOs. The CBL mentors played a key role in mitigating this risk of breaking the constructive alignment.

The contribution of the mentors go beyond steering the learning experience. Through their interaction with students, Guiding Questions were rewritten, Challenges were redefined, and students were continuously prompted about their responsibility in defining their own learning experience. More than simply steering the learning experience, the mentors shared ’tacit knowledge’ on how to systematically approach the investigation of a given problem/challenge. Although difficult to measure, we can’t ignore the importance of the mentors in helping students develop their ’researcher approach’. Therefore, beyond ’feasibility’, the mentors contribution also had an impact on what and how students learned during the course. Finally, although the ’cost’ of this added measure may seem relevant by some, it’s important to consider the support for tacit knowledge transfer brought by such a measure.

3.2 The Need for adapting CBL phases

The SIS-CBL edition (2022) had 16 groups of four students each. The CBL mentors were available from weeks 5-9, and, since they were not specialists in all topics (and challenges), their responsibilities were mainly related to the students’ learning experiences within the CBL framework. Table 1 presents a summary of the traditional and CBL milestones expected to be observed from each participant group of the SIS course, in accordance with the CBL phases (engage, investigate, and act).

In the engaging phase, CBL mentors prioritized group involvement and participant excitement for the challenge. Given the students’ enthusiasm in solving the challenge

Table 1. CBL phases and milestones throughout mentoring and project development.

CBL Phases	Expected and observable milestones
Engaging	**(1) Classical CBL:** (I) Select an application case, (II) Brainstorm essential questions and formulate the main problem to be further investigated (Select a ”topic”), and (III) Pitch idea to the case owner and receive approval to investigate, develop, and implement their ideas. **(2) Adapted CBL approach:** (I) Formulate essential questions, which could not be closed questions, (II) Ensure that all participants within each group are involved, engaged, and motivated with the selected main problem to be investigated, and (III) Ensure that the potential selected challenge is within the scope of the SIS course and is something that can be tackled within the course's timeline.
Investigating	**(1) Classical CBL:** (I) Select formal materials (e.g., books and research papers) to refer to the proposed solutions, and (II) Whenever possible, identify comparable work and establish a benchmark for the selected methods. **(2) Adapted CBL approach:** (I) Provide a preliminary solution to the challenge, (II) Frame the challenge as an action that will lead to the next CBL-phase rather than an open (or closed) question, and (III) Reflect on the ongoing work.
Acting	**(1) Classical CBL:** (I) Implement the suggested solution, observe, and (II) Present conclusive results in a written report and oral presentation **(2) Adapted CBL approach:** (I) Ensure that the challenge selection and the main methods and experiments used to address this challenge are highlighted in the final report and presentation. (II) Ensure that students and case owners understand the contribution and relevance of the proposed solutions, particularly when comparing the final solution with the preliminary solution provided in the previous CBL-phase (investigating), and (III) Reflect on the tasks performed within all CBL framework steps.

they highlighted, the CBL mentors helped them refine their important questions during brainstorming. This was important because most of the students' inquiries were closed or outside their goals. The CBL mentors gave case owners a brief report with comments after each group meeting to help them decide whether to accept a challenge and address any potential issues with group formation or team member participation. After the engage phase, each group had picked a clear and preferred challenge with crucial questions related to the course curriculum.

During the investigation phase, CBL mentors ensured that (1) the groups' challenge was accepted by the case owners; (2) they had an initial idea of how to approach the challenge (preliminary answers); and (3) students knew where to look for potential elements to get to solutions (e.g., tutorials, books, articles). Thus, in the investigation phase, assisted by CBL mentors, students merged the essential questions and related them to the main challenge, recommending materials (or lecturers) to address these questions, and analyzing with group members the feasibility of their solutions to their challenges, considering project milestones (deadlines). After each meeting, case owners and lecturers received student reports.

In the action phase, CBL mentors helped students choose a solution design orientation, implement chosen approaches, and evaluate their results. Students were in closer contact with the case owners, who were experts on each industry problem, while the CBL mentors guided them through the challenge management steps and provided constant feedback on how to incorporate the findings into the graded project deliverables (presentation and report). Case owners and instructors received a summary of the CBL session. The CBL mentors were present for project presentations and saw that most groups followed the CBL storyline: presenting the challenge, how they identified their interests and problems, and the proposed solution.

3.3 Students' satisfaction and perceived quality

This study compares the M-SEQ students filled in the two most recent SIS course editions. Seven students (16.3%) completed the experience questionnaire in 2021, and 10 in 2022 (17.5%), both within the expected average. The M-SEQ has two main categories of questions (described in Table 2): first, students must score certain criteria, then open-ended questions about course topics. These open-ended questions are divided into three categories: teaching practices that were useful or counterproductive, course improvement suggestions, and general comments.

The 2021 and 2022 SEQ mean, median, and grades did not vary significantly, and the students' general satisfaction with the most SIS-CBL version of the course is slightly lower[1]. Due to the low M-SEQ response rate, the median[2] usually drops less than the mean. SIS-CBL also had slightly higher mean scores for general (Q4-5)[3], marking (Q6)[4], teaching (Q7-10)[5], and testing (Q11)[6] questions. Students were more interested with course relevance to their degree than course-prior knowledge and course-learning objectives alignment.

According to open-ended questions, CBL and CBL mentors helped students create and implement their projects (OEQ1). They said they would have had a better experience if they had had access to the data earlier in the course or when choosing their project topic. In both versions of the course, students said tying lecture topics to projects and better organizing/distributing due dates will improve their SIS course performance (OEQ2). Finally, students say a storyline and potentially reducing the course's content would aid learning (OEQ3). Some students also regarded CBL as a promising tool for the SIS curriculum and suggested improving the lecture-project relationship.

Table 2. Questions of the Students Experience Questionnaire (SEQ).

Question #	Question description
01	Did I understand the learning objectives and assessment criteria?
02	Were course topics pertinent to the educational curriculum?
03	How well did the content of this course align with your prior knowledge?
04	Will the knowledge and skills acquired in this course quickly become obsolete?
05	Was the amount of time I spent studying for this course proportional to the number of credits granted?
06	How many points would you assign this course?
07	Did the instructional activities encourage me to study?
08	Did the faculty encourage me to think independently?
09	Did I feel that the instructor had a good understanding of how the students were coping with the subject matter and acted appropriately when required?
10	Did the course's feedback provide sufficient information for further study?
11	How would you rate the online examinations in this course?

[1] 2022 mean: 6.6/10.0, 2021 mean: 7.0/10.0.

[2] 2022 median: 6.0/10.0, 2021 median: 7.0/10.0.

[3] 2022 mean: 3.5/5.0, 2021 mean: 3.7/5.0

[4] 2022 mean: 6.7/10.0, 2021 mean: 6.6/10.0

[5] 2022 mean: 3.5/5.0, 2021 mean: 3.4/5.0

[6] 2022 mean: 7.1/10.0, 2021 mean: 6.4/10.0

3.4 Discussion

Research projects offered as part of a CBL approach can have a positive impact on students' performance. By engaging in hands-on projects that tackle real-world problems, students develop practical skills that complement the theoretical knowledge gained in lectures. Additionally, working on projects in groups promotes collaboration, communication, and critical thinking, skills that are highly valued. Moreover, students are encouraged to take ownership of their learning process by conducting research and finding creative solutions to problems, leading to increased motivation and engagement. This approach also provides students with an opportunity to apply their knowledge in a meaningful way, leading to a deeper understanding of the material.

The CBL mentoring process plays a crucial role in creating an enhanced learning environment. Mentors can provide guidance and support to students throughout the project development phase, helping them stay on track, identifying gaps in their understanding, and offering feedback on their work. This process also encourages students to take responsibility for their learning and develop self-directed learning skills. Mentors can also provide industry insights and connections, exposing students to potential career paths and helping them develop professional networks. By creating a supportive environment that fosters collaboration, critical thinking, and problem-solving skills, the CBL mentoring process helps students develop the confidence and skills necessary to tackle complex real-world challenges.

The challenges selected from predefined case owners can be effective in resolving real-world problems using CBL. These challenges are designed to be relevant and applicable to real-world scenarios, ensuring that students develop skills and knowledge that can be applied in the workplace. Additionally, by collaborating with case owners, students gain insights into the challenges and constraints faced in different industries, leading to a more nuanced understanding of the material. The challenges provide a structure for the project development process, helping students stay focused and on track. By leveraging the expertise of case owners and integrating real-world challenges into the CBL approach, students can develop a deeper understanding of the material, acquire practical skills, and build their confidence in tackling complex problems.

4 CONCLUSION

This paper has addressed two central questions for educators who are interested in implementing CBL while maintaining constructive alignment in their course design. The first question addressed how to ensure that the results derived from addressing student-defined challenges are successfully aligned with the course's intended learning outcomes. The second question focused on how to utilize these results as evidence of learning and as an assessment component. Our paper has presented our experience and lessons learned in applying CBL to the redesign and execution of the Smart Industry Systems course for Master programmes at the University of Twente. We have demonstrated that it is possible to implement a version of CBL while maintaining proper curriculum coverage and Constructive Alignment, and we consider valuable to other educators seeking to adopt CBL in their courses.

The presence of CBL mentors or specialists in a CBL-based course is crucial for the success of the learning experience. These mentors can provide guidance to both students and instructors, ensuring that the CBL approach is implemented effectively and that the desired competencies are being developed. Furthermore, having mentors or specialists who are knowledgeable about CBL can help identify potential challenges and provide solutions to overcome them. The need to meet formal evaluation and accreditation requirements may sometimes cause instructors to modify the CBL approach or include traditional teaching methods to satisfy these requirements. However, as the use of CBL becomes more widespread, it is essential that its principles are maintained and incorporated into the evaluation and accreditation processes. By doing so, we can ensure that CBL is recognized as a valuable approach to learning that can prepare students for real-world challenges and promote lifelong learning.

The implementation of a CBL approach can face limitations when attempting to align with a rigid curriculum that emphasizes fixed learning objectives. This can create a challenge in connecting CBL with Constructive Alignment, which seeks to align learning outcomes, assessment methods, and teaching strategies to achieve desired learning outcomes. The CBL approach prioritizes the development of specific competencies, which may not always align with the predetermined learning objectives of a curriculum. Therefore, the challenge is to find a way to integrate the CBL approach with the curriculum while still ensuring that students meet the required learning objectives. This requires a flexible approach to curriculum design and specialized human resources that enable the incorporation of CBL principles while maintaining the integrity of the overall curriculum.

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