The need to extend CBL courses over longer periods - a test case on a CBL course on IoT

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***Abstract* – We report on our gained insights from the development of a challenge-based learning (CBL) line focusing on entrepreneurship and internet of things (IoT) technology. We observe that student engagement and quality of project work and learning has significantly been improved when the original one-course CBL experience has spread out over three consecutive courses. We further suggest that for the case of multi- and interdisciplinary learning lines, focus on the different disciplines in different courses, encourages students to engage in aspects of CBL outside their own discipline, hence better fulfilling the design goal of true multidisciplinary learning.**

Keywords— CBL, time on task, electrical engineering, industrial design, innovation sciences, real-life challenges.

I. Introduction

The use of alternative instructional modes such as challenge-based learning (CBL) has been gaining significant traction in academia around the globe[1]. Earlier versions use the terminology problem-based learning (PBL) to illustrate the learning is achieved through the solving of problems[2]. CBL originated from the Apple classroom experiments [3] and was, as the creators of the method suggested, a consequence of several technological and societal developments [4][5]. At its heart, CBL suggests that instead of students being passive observers in the classroom, they must actively search for missing knowledge to solve a specific challenge [6].

In the past 5 years, Eindhoven University of Technology (TU/e) has embraced CBL as its go-to method to increase students' engagement with their learning journey and create a more interactive learning environment where students take ownership of their studies [7]. In parallel, in its restructuring of the bachelor college in 2012, the TU/e has opted to include compulsory 15 ECs for students on cross disciplinary learning lines focusing on aspects of engineering outside the majors under the acronym USE [8].

Through a collaborative effort of lecturers from three faculties, i.e., Electrical Engineering, Industrial Design, and Industrial Engineering & Innovation Science, we have explored using CBL methods to teach combined aspects of Internet of Things (IoT) technology, design thinking, and product creation. What started as an eight-week condensed course where students needed to go through all stages of product development, from ideation to validation and business development, has evolved into a seven-month learning trajectory stretching over three consecutive quarters. In this fully designed learning journey, the different phases and associated learning objectives of going from a well-defined challenge to a validated product are getting sufficient time to be taught and experienced in teamwork. By mixing students with different backrgounds, I.e. from different schools, the multidisciplinary learning is enhanced.

We observe through student surveys and the maturity of concepts and MVP products, that the full impact of CBL, as an instructional method, is only realized when students have enough time to explore the different phases of the design cycle leading to innovation—and the freedom to choose their solution to the challenge. We believe that our seven-month learning line, as well as several other similar learning trajectories emerging from other faculties in the TU/e, serve as an excellent example of how best to use CBL as an instructional model. We recommend that other universities aiming to employ CBL in their engineering curriculum carefully consider allowing their CBL courses to stretch over at least four months and ideally longer—and to provide teaching teams with the resources to guide this journey over time.

II. The Single Quarter Variant

The IoT CBL was initiated by the Electrical Engineering (EE) department in 2017 as an alternative learning experience on IoT and networking. While the course was led by lecturers from Electrical Engineering, guest lecturers from the departments of Industrial Design and Innovation Sciences were involved in the planning and also in giving lectures in the course. The stated ambition of the course was to offer students a hands-on experience to understanding the basic networking aspects of IoT. To this end, it was chosen to give students a design challenge within the confines of the problem of indoor localization. Student did have the freedom to design their own unique hardware and software which resulted in a lot of creativity in solutions created. Also, on the software implementation side, the different groups made different design choices which gave all participants a good overview on how one can approach the problem [9]. Additional learning objectives concerning the design aspects (such as UX and UI) and aspects concerning the business aspects of the development of technological solutions were neglected in the project, due to limited time and the homogeneity of the student groups (all EE students). Due to the small number of students, and low participation rate in the course evaluation it was not possible to assess the learning during the course.

In the 2nd version of the course, in 2018, we allowed students to define their own IoT devices. Since it was now up

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to the students to decide what IoT enabled device they wanted to develop, it became critical that the different teams will be able to not only demonstrate their solutions but also defend their design choices and be able to support the claims of a commercial value to the innovation. This inevitably meant that there was time pressure on the teams to cover all aspects within the allotted 8 weeks. And while the projects emerging from the course were more creative, students complained: "…Brainstorming can take a long time and especially if we have to iterate (on our ideas, OR) then 8 weeks is very tough…" (taken from course survey). Based on this and more student feedbacks, and the ambition of the university to create multidisciplinary learning lines, we launched the IoT learning line in 2020.

III. IoT LEARNING LINE – DESIGN AND CONTENT

The design phase of the new learning line combined the skills and know-how of three different disciplines, Industrial Design, Industrial Engineering & Innovation Sciences and Electrical Engineering.

The planning phase for the integrated learning line was quite extensive with a joint planning and several approvals from TU/e committees. It was important to facilitate a linking of the three courses beyond the conventional prerequisite-admission linking (students need to pass one course to be admitted to the next): we wanted student teams to bond in the first course, then go together through the learning line, to train professional skills in joint concept development and problem solving in a group context, but also to let them benefit from their shared mindset, ambition and momentum once a group starts to "click". This is a somewhat risky endeavor as a weak might not make it to the next course or group members might only need the passing credits of a single course and would then leave the team. For this reason, we planned for an explicit "regrouping" stage at the beginning of the second and third courses, in which new team members could be found or groups could split up and member would find new groups.

The resulting list of student experiences is given below:

1. Idea creation – Creative brainstorming and the giving and receiving of constructive feedback
2. Idea "validation" – in the first course, students will go through an ideation stage, validate their ideas in patent literature and in use cases and then expose their ideas to the other students in a "marketplace"
3. How to define product features? Understanding the concept of minimum viable product (MVP)
    a. Technology exploration
    b. Technical feasibility study; technology readiness of components of the concept
    c. Platforms and infrastructure for connectivity
4. How to make a business plan? What level of freedom-to-operate is there on the technologies involved in the product/service concept? What is the (added) value proposed? Who are involved in the adoption decision?
5. Doing market research and understanding adoption factors and the buying process
6. Design-based on user experience and user interfaces
    a. Contextual exploration
    b. Creativity in the product design process; What parts of the product/service concept can be protected by IPRs?
    c. Value-based methods in design
    d. Prototyping experiential artifacts
7. Product Marketing strategy.
8. Funding; Value creation for investors and crowd.

Based on the expected student experiences and learning targets we have created three different courses which help the students along their journey of discovery. Below are the abstract descriptions of these three courses:

Course 1 – From idea to a blueprint (Lead ID)

The first course in the learning line aims to install/awake in students the entrepreneurial spirit. This will be done by allowing the students to spend considerable time on idea creation as well as idea analysis and peer review/feedback (like small "startup" companies). Through this group process, we expect student to become more engaged with the eventual technology challenge they will chose to tackle and put the required effort to push its development in an accelerated process to a blueprint by the end of the first course.
Lectures will be given on fundamental aspects of design and a general set of technical criteria for all projects will be laid down. Also lectures on ideation and constructive feedback will be given.

Course 2 – Concept vs reality (Lead EE)

The core of the learning line will take the groups from the concept to a working prototype which has been carefully designed and is clearly supported by the identified user needs and problem definition. Aspects of design and technology will be intertwined which will require a fast-paced development of the right features into a product ready for validation. A focus on MVP and critically separating the nice to haves from the essential will lead to an improved product offering/working prototype.

Course 3 – Validation to sales (Lead by IS)

In the 3rd and last course comprising the IoT learning line the focus would shift from idea creation and validation to the operational aspects of bringing a innovation to the market. The groups will need to consider what the buying roles and process typically consist of and what the adoption factors are for those involved in the process. This marketing research is the start for defining the marketing strategy, that is to be complemented with market information and data gathering on the market segment, target groups and perceived positions of rivalling products/services in the target market. A media campaign is to be designed based on the analyses. However, the starting point of the 3rd quarter and thus the course are a set of solution validation interviews with users/customers to validate and optimize the teams' minimum viable product (MPV). It means that they will need to go into the real world with their innovative solution and test how it addresses the original challenge under real-life conditions.

IV. Application in Three Iterations

The IoT use learning line (ULL) was launched in September 2020 in the middle of the COVID-19 pandemic and has run in its current format for the past 3 years. Below we share our observations and numbers concerning the course evolution and its outcomes:

- Student participation population composition

In figure 1 we show the number of students participating in the learning line across the years:

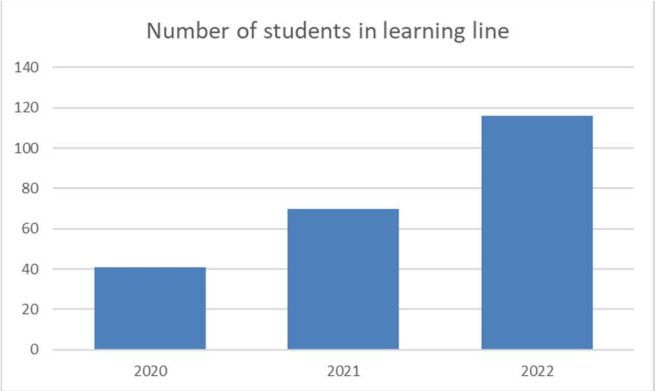

Figure 1: Total number of students annually from 2020-2022

We observe a steady growth in the number of students with a growth factor of ~60% year on year. This growth is even more impressive in light of the fact that the 2021 and 2022 versions were given in the midst of the Covid pandemic. As the total number of students in 2nd and 3rd years of their bachelor (typical student population) has not grown, the almost tripling of the total number of students is a clear indication that the topic and set-up of such a CBL experience is attractive to students.

In figure 2 we plot the distribution of students across the different bachelor progams in TU/e.We observe strong shifts in the participation of students in terms of variability and multidisciplinarity. We have seen great improvements in the composition of student teams, with a significant growth in the number of students from computer science. The heterogeneity in student population also supported the ambition to get students from different disciplines to collaborate in the learning line [10].

The learning line was originally designed as a continuum of 3 course so students (aside from one or two students with specific issues) took all three course in a row. This helped create team identity and stronger identification of student with their products. Due to the nature of the course assessment, >95% of students passes the course in the first go without a need for re-sits.

In terms of the process of developing the learning line, also there several iterations were needed to achieve an optimal student experience. The first iteration concerned the switch from the single course to extended CBL student experience across three quarters. The student team challenge was to develop an IoT product for the aging society. The first course was delivered by lecturers from ID and introduced the students to user interviews, ideation techniques and how to identify “a problem worth solving" for a potential customer. In the 2nd course, led by the lecturers from EE, the teams developed a working product solution addressing the problem, based on a IoT platform of their choice. In the 3rd course, led by lecturers from IE&IS, the business side was taught using brief lectures and by encouraging the students to further develop their products with customer and market data. Professional consultants from an investor company acted as coaches throughout all three courses. The company offered support, also hoping to get access to young talent and startup ideas. However, may teams failed to make optimal use of these coaches. A survey showed that few teams used them, when they did, these teams benefitted of the feedback and the opportunity to pitch their work to experience business mentors. The information was used to urge, in line with effectuation thinking, other teams to also better make use of the resource.

Despite close coordination of the team of professors there was a serious overlap in the course materials. Business model concepts, for instance, were present in all courses. More importantly, many student teams failed to really get to a working prototype in course 2.

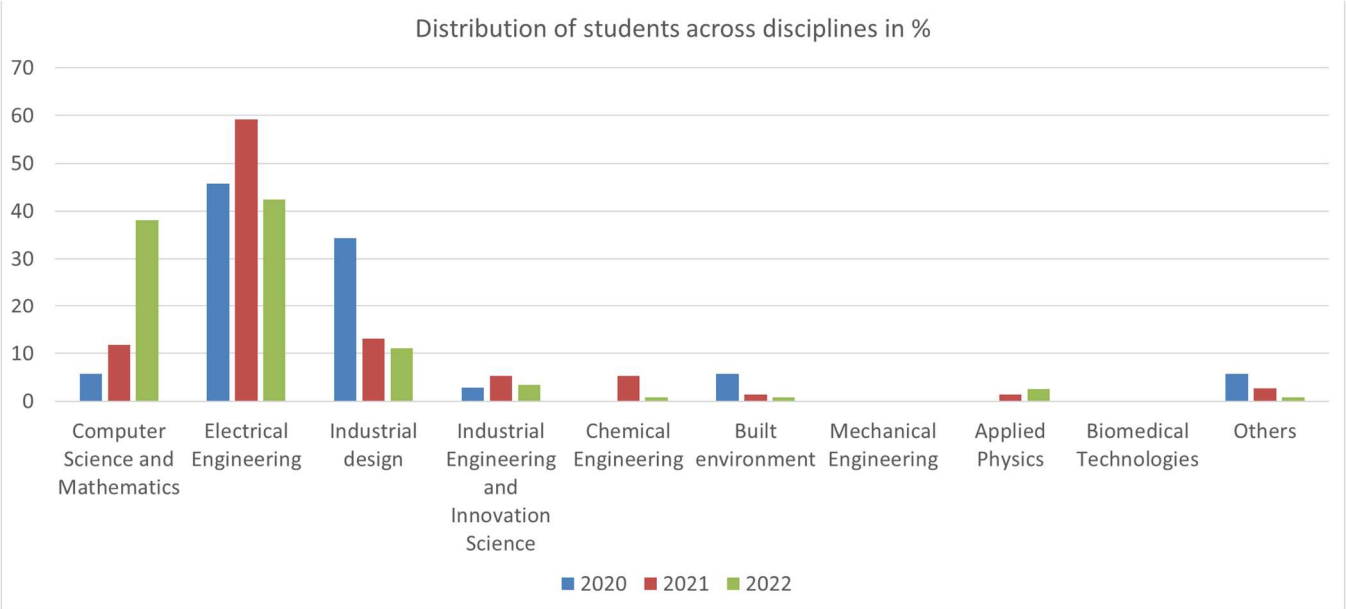

Figure 2: Student distribution per bachelor major

This hindered progress in course 3; students could not show their prototype to potential customers an solicit feedback. Students liked the crowd-funding campaign they had to develop as part of course three but saw too much overlap with course 1, where also price and cost issues (business model related) had been brought up.

- Learning from iterations to adapt course content

The following year, a clearer and more focused challenge was chosen: Connected Devices for Health. We reduced the overlap between courses and made an extra effort to ensure students finished an initial prototype early-on in the course sequence. These changes had a positive effect on the learning progress and experience; students reported more cohesion in learning activities and less repetition in content. The investor company, who had been participated in the first iteration, reconsidered their position, and limited its contribution to two consultants. In reflection, the professional coaching was helpful, but too focused on the pitching and investor perspective. What the students needed was support in developing strong ideas that would stand the test of being exposed to real-life end-user feedback. Next to that, a group of professional stakeholders would help gain access to relevant end-users and drive the feedback process also from a perspective of how to integrate new solutions into existing systems in the market.

In the final iteration, we have decided to work with a problem owner who could present the challenge and support the student teams. Having domain experts on board would add relevance and focus, and increase access to a relevant network of actors and resources. The student teams were instructed to make an IoT product to help the elderly be safe and live independently. So, rather than selecting a grand challenge (e.g., climate change) the decision was made to focus on product innovation instead to ensure the bachelor students could develop and test a small, yet real product.

The support for this project in terms of problem owner was a representative of the municipality of Eersel in North Brabant together with two commercial entities in the area of home automation for healthcare and a connectivity partner (Akkedeer, 5G Hub). The assignment given to students by the problem owners was to engage with the members of the community and develop solutions to problems elderly might be facing. The opportunity to engage with real users and the great interaction between young students and the retirees of Eersel has delivered 25 different developing concepts that were further developed by the student teams throughout the learning line.

All-in-all through these iterations we have been able to deliver a CBL learning experience which to our opinion best reflects on the spirit of CBL education and maximizes students benefits from the courses.

- Project outcomes and societal impact

While the first 2 versions of the ULL focused purely on assignments defined by the teachers (Y1 the theme was aging society and in Y2 the theme was health), in Y3 we have opted to team up with the 5G Hub and the municipality of Eersel in North Brabant. The assignment given to students by the external customers was to engage with the community and develop solutions to problems they are facing.

The opportunity to engage with real users and the great interaction between young students and the retirees of Eersel has delivered more than 25 different technology solutions. We asked the problem owners to inquire the end-user community about all ideas and they voted on the most promising/exciting technology offerings. As a promising follow-up, the municipality has invested over 50.000 EUR to offer selected student teams the means and coaching to further develop their ideas into viable products. This could not have happened without students spending significant time in understanding the problem (by engaging with future users) as well as carefully making design choices when building prototypes for demonstration purposes.

- Student feedback and testimonials

Below we include some of the testimonials of students participating in the course in 2022/2023 edition reflecting on the main ideas discussed above:

- *I liked that we are able to explore something that is relevant today and the amount of creativity we are given*
- *How much freedom there is and how much time you get to fully develop and work out your ideas*
- *Nice course, I had fun and I felt I have actually learned something (unlike the mess Engineering Design is). Really makes me happy and I enjoy it.*
- *I liked the fact that we were very free in choosing what project we wanted to work out.*
- *I liked going into the field in order find new ideas*
- *I like the way the course makes us understant how complex is the path from coming up with an idea and make concepts for it. The course is very useful for those who maybe want to become entrepreneurs or work in a start-up.*

V. Conclusion

In this paper, we describe the implementation of Challenge-Based Learning (CBL) in the higher education context of a Dutch technical university. We designed an applied IoT technology course in a framing of a new product development process with additional aspects of ideation and concept development, design and iterative prototyping, marketing and related business aspects, and finally professional skills around pitching and group work. We reflected on the first two iteration of this learning activity and describe how we transition it into a three-course, seven-month learning line that allows student teams to deepen an entrepreneurial experience connecting IoT technology, design and business skills, and a societal impact issue. Our contribution is to showcase how university education (1) can be successfully implemented in a challenge-based manner and (2) combine diverse education requirements, even partly attension, in a coherent offering that is evaluated well by students over several years.

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