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EXPLORING THE FABRICATION LAB CONCEPT FOR LEARNING SUSTAINABLE CO-INNOVATION IN INDUSTRIAL ENGINEERING EDUCATION – AN ACTION RESEARCH CASE FROM AUSTRIA

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ABSTRACT

According to recent studies, cooperative innovation between universities and industry, especially with small and medium firms, is not as frequent as expected. Case-studies of regional innovation systems have shown that open access to state-of-the-art research infrastructure, services, skills and activities are needed to achieve long-term innovation partnerships. Co-innovation requires particular skills beyond technical knowledge, which are not always addressed in engineering curricula at university. Fab labs are a concept that potentially fosters students in the acquisition of such skills. In this paper, we describe our experiences in designing, building and running a fab lab as a new element for industrial engineering education at our university in Austria.

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1 INTRODUCTION

Regional innovation systems (RIS) can be understood as “a set of interacting private and public interests, formal institutions and other organizations that function according to organizational and institutional arrangements and relationships conducive to the generation, use and dissemination of knowledge” (Doloreux 2003). The basic idea is that different stakeholders with academic, entrepreneurial and governmental background and motivation are the foundation that encourages a region to develop innovative capability and competitiveness (Gertler 2010).

Based on a multiple case-study, the European University Association (EUA) recently reported that universities and companies are changing from linear innovation models to co-creative, systemic approaches with external partners (EUA 2019). Their report outlines major determinants of these new forms of cooperation observed at European universities and their partners in regional innovation systems. Among other determinants, case-studies have shown that access to expensive large state-of-the-art infrastructure and technical facilities as well as equipment with technical support staff and joint institutes or labs are needed together with joint research activities on all levels, reaching from student thesis projects to joint product development, in order to achieve long-term research partnerships.

Moreover, co-innovation with enterprises is not self-perpetuating, as it requires particular skills beyond technical knowledge. Research shows an increasing need for sustainable innovation competences among engineers, such as creativity, problem-based thinking and a sense of responsibility, which inevitably influence teaching concepts and goals in engineering education (Piippola et al. 2012). According to different studies in engineering education research, however, engineering curricula often fail at addressing such competencies, thus mainly focusing on narrow technical specifications (Cropley 2015) and ranking a broad theoretical knowledge as a foundation for getting involved in further engineering courses (Dym et al. 2005).

In this paper, we describe our findings from a recent case in Austria, where we have explored the concept of fabrication labs as an approach to provide ongoing engineers with innovation competencies during their studies, thus promoting sustainable innovation with other stakeholders in the regional innovation system in Austria. In the next sections, we describe in short the basic theoretical background of our approach, the methodological approach and the main findings and impact we experienced on industrial engineering education.

2 BACKGROUND

2.1 Challenge-Driven Education and skills for sustainability

In their study, the EUA (2019) identifies a change in the innovation approach of stakeholders in the innovation system, thus shifting from technological to challenge-driven innovation. This often takes place in common spaces with an increased focus on sustainability and can be also reflected by educational approaches at university, e.g. by Challenge-Driven Education (CDE). The latter not only aims at developing solutions that are sustainable under an environmental, societal and economic point of view (e.g. Rosén et al. 2018), but also allows students to approach societal challenges in all its complexity. Malmqvist, Kohn Rådberg, and Lundqvist (2015) highlight how this feature of CDE uniquely allows students to train important additional skills, reaching from teamwork to addressing societal issues. Working on real, interdisciplinary challenges in cooperation with actors outside university, moreover, provides students with professional skills for their future career (Klaassen et al. 2022).

In general, the underlying approach of teaching students in a cooperative context with companies also contributes to UNESCO's Sustainable Development Goals (SDGs) (UNESCO 2015) in multiple ways. For example, CDE allows ongoing engineers to actively practice inclusive innovation at a regional level, thus supporting SDGs n. 8 and 9. Student cooperation with other stakeholders in the innovation system contributes to SDG n. 17 and allows to address challenges that are shared by different actors in society. Sharing knowledge across disciplines to develop sustainable solutions supports responsible consumption and production (SDG n. 12).

2.2 Fabrication lab concept

The concept of fabrication labs (fab labs) basically refers to workshops that offer open access to low-level manufacturing and prototyping equipment (Gershenfeld 2012). The basic idea is to open up access to often expensive manufacturing technologies, therefore supporting bottom-up innovation. Meanwhile, fab labs have spread around the world and are recognized as potential innovation facilitators (Cattabriga 2020). The Interreg initiative of the EU (2022) highlights different case studies showing that fab labs are a suitable instrument to promote university-industry collaboration and support regional innovators, also fostering prototyping, knowledge sharing and the training of new skills.

3 APPROACH

Our university is located in a relatively small city in Austria with a high density of industrial firms. The regional government strives to encourage innovation activities and cooperation between different stakeholders. As part of this effort, infrastructure for joint research and development has been publicly funded. Therefore and because of the advantages mentioned by Gershenfeld (2012), we decided to establish a fabrication lab at our university.

In this paper, we will describe our experiences from conceptualizing, building and running an open fab lab at our university with regard to enhancing engineering education. The whole project was pursued in a way that can best be described as an action research approach. Action research as proposed by Gustavsen (2005) aims at getting involved in a (social) situation, understanding it, improving it and creating knowledge from shared experiences made during the process of improvement. While conceptualizing, building and running the fab lab, we conducted different steps in an iterative manner, flipping constantly between a more observing position to understand the situation, problem and effects of measures and a more intervening position, where we developed and implemented measures. For example, in order to identify expectations and needs of the different stakeholders involved, we organized meetings and conducted surveys both with students and other potential user groups throughout the project. All feedback and results from discussions and surveys were documented and analyzed (see Erol and Klug 2020, Böhm et al. 2022).

The project plan was set up to achieve three main goals, (1) the setup of the whole fab lab infrastructure (see Fig. 1) including the building, work places, machines, amenities, (2) the development of service offerings and processes to support co-innovation activities and especially educational activities in co-innovation and (3) the growth of a community of corporate and university users. Given the main goals, the corresponding work packages have been conducted partly in parallel, which allowed us to shorten the overall project time and to constantly adjust infrastructure to service needs and vice versa. Also reach-out activities to corporate users, faculty and students started in an early phase, e.g. engineering students have not only be involved through feedback

cycles but also as part of the team that designed, built and run the lab, corporates have been invited and shown around during build phase.

Fig. 1. Newly-built fabrication lab located in a former factory building (Sept 2021)

4 RESULTS

Results of the project have been grouped according to their type of impact. Accordingly, we describe experiences and lessons learned from designing, building and running the fab lab during the period from Jan 2021 to Jan 2023 (19 months, overlapping design phase: 6 months, build phase: 6 months, run phase: 16 months).

4.1 Impact on regional innovation infrastructure

The fab lab was built on around 1,100 sqm in a former factory building near to our university campus and in the center of an industrial area. It consists of 7 sub labs, each focusing on a specific technical area of expertise. In particular, these are: (1) Metal Lab, (2) Wood Lab, (3) 3D Printing Lab, (4) Electronics Lab, (5) Textile Lab, (6) Laser Lab and (7) Robotics Lab. All these sub labs have workplaces equipped with a computer and domain specific software to support digital workflows from modeling and simulation to manufacturing of prototypes.
The actual status of service offerings developed can be seen in Table 1. Services are targeted at different user groups identified, e.g. corporate users as industrial enterprises, start-ups and research institutions, private users and students. A distinction is also made between services for expert users and novices needing extra support, e.g. a basic technical training on a particular machine or manufacturing technology. Although they are tailored to specific user groups, most of these services are open to all users, thus enabling encounters and exchange between students and other user groups as well. Service offerings were developed based on qualitative interviews and a review of service offerings from similar fab labs. Results were subsequently validated, adapted and extended to suit specific needs of the user groups. For this purpose, discussions in the core team, interviews with students and other potential user groups were conducted.

Table 1. Implemented service offerings in the lab (by Jan 31st, 2023)

Service offering	Description	Staff involvement	Target group
Self-service for machinery and equipment	*Users use machinery and equipment on their own 24/7*	*Self-service*	*All target groups*
Managed project space	*Users use blank space for large projects and may use machinery and equipment*	*Self-service*	*Industrial enterprises, start-ups, research institutions*
Basic technology trainings	*Trainings to learn machinery and equipment in the lab*	*Internal staff*	*All*
Advanced technology trainings	*Trainings to learn advanced techniques to create prototypes and products in the lab*	*Internal staff and external partners*	*All*
Innovation workshops	*Workshops to learn new methods and techniques in product development*	*University staff and external partners*	*Industrial enterprises, start-ups, research institutions*
Community meetings	*Informal get-together for news and idea exchange, networking*	*Internal staff*	*Students, private persons*
Competitions	*Organized idea challenges, e.g. hackathons, challenges*	*Internal staff, university staff and external partners*	*Students, industrial enterprises and services, start-ups*
Conferences	*Organized special topic conferences with interactive parts*	*Internal staff, university staff and external partners*	*Students, industrial enterprises, start-ups, research institutions*
Corporate presence	*Enterprises of every size can present themselves in the context of the lab*	*Internal staff*	*Industrial enterprises, start-ups*

4.2 Impact on cooperation with regional industry and community

Reach-out activities carried out from the very beginning of the project supported us in introducing the new infrastructure and service offerings among stakeholders in the region. In order to foster co-innovation, we organized several networking events, e.g. a conference (Inventors Day) dedicated to address inventors in the region and connect them with industrial enterprises, founders, investors and students. Another event (Circular Design Day) brought together pioneering companies and students in the field of circular design. We also organized hackathons and challenges and invited companies to pose challenges and students to jointly develop ideas and solutions. Here, we experienced a strong interest from industry to meet talents of the future. However, due to a rather large amount of such events, students need to see a particular benefit to be willing to participate.

To date, the fab lab has also hosted three large-scale publicly-funded innovation (R&D) projects with regional industry in automotive, aircraft and furniture manufacturing sectors. These projects used both equipment and project space for a limited time. Other small-scale development projects have been conducted in cooperation with local companies, e.g. the development of 3D-printed furniture feet. Students are involved in these projects, e.g. they developed an iron bird mock-up for a new electrical transport drone as part of a larger research project.

Since the beginning of 2023, 24 regional companies and institutions fund the lab. 9 companies actively use the lab, under which 3 are start-ups, one is an individual company and 5 are large enterprises, as well as 2 private research institutions. 4 of the companies are users and sponsors at the same time. Companies mainly perform development and prototyping activities and want to attract personnel and potential partners for R&D. A regional high school uses the lab to hold workshop classes, 42 private users have joined the lab and use it on a regular basis for private projects, 56 faculty members have registered to use the lab for teaching their courses (or parts of) in the lab and 117 students from our university have joined as they do or plan to accomplish student projects, bachelor or master theses (see Fig. 2).
The fab lab is now an established regional innovation infrastructure and is listed in the registry of significant Austrian R&D infrastructures.

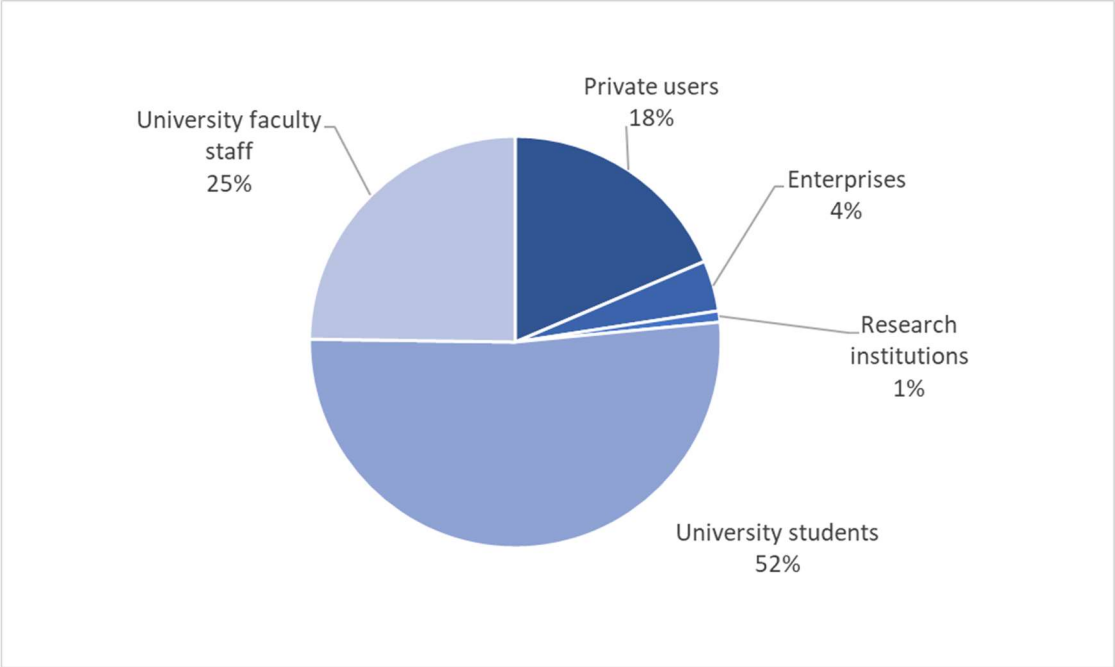

Fig. 2. Community (user groups) of the fab lab, n=226 (by Apr 30th, 2023)

4.3 Impact on engineering education

From the very beginning, we involved students of industrial engineering programs. Two industrial engineering students were employed part-time and became part of the core project team. We also created a volunteer scheme and invited students from the engineering faculty to participate in the project. From an initial group of around 20 volunteers, around 10 students remained and supported us to build and start up the fab lab. We held monthly meetings to inform them about the progress, collect feedback and distribute tasks. Students' technical background was diverse and considered in distribution of tasks. After opening the fab lab, four volunteer students were employed permanently to support us in user management, maintenance and trainings. We learned that students with a strong background (educational or autodidactic) in making or manufacturing preferably joined us. Those students that remained in the long term were students that used the fab lab for their own projects at university or privately. A short geographic distance between home and university campus was another reason that favored student participation. Some students quitted the initial team due to time

constraints because of commuting or additional jobs. The fab lab became a meeting place for students. Especially when they worked on projects, we observed vivid knowledge exchange across students from different engineering programs, e.g. mechatronic students helped industrial engineering students in bug fixing at a 3D printer controller unit. Three of our student team members completed their thesis about particular problems and respective solutions they developed in the fab lab, e.g. the efficient scheduling and automation of print jobs in the 3D printing lab.
After opening up the fab lab (Sept 2021), lecturers were invited to use it in courses and also invite their students to use it for bachelor and master thesis projects. The fab lab's unrestricted opening times (24/7) proved to be useful, as students were not bound to the presence of a lecturer and limited opening hours to complete their projects. However, after a first rather uncontrolled run on the lab, we had to introduce a workflow that ensured that students got authorization form their study program head and had to pass a basic technical and safety training before getting open access. The basic technical and safety trainings are open to all user groups. Given that, students get in contact with professionals and corporates and are able to learn from each other.

Fig. 3. Students working on rocket launch system (3rd semester)

Fig. 4. Students working on a mobile barbecue (4th semester)

Today, students of the industrial engineering study program use the lab in different ways. In the first semester, in the course of a lecture on manufacturing technology, they get a practical training on different manufacturing technologies in the fab lab. The training follows a CDE approach in which students need to manufacture a given product, e.g. a home tool box, that involves different machines, equipment, materials and therefore are able to apply theoretical knowledge to a real world problem. In the fourth semester, they are able to use the fab lab in the course of a lecture on product development and engineering (see Fig. 3 and 4). They are encouraged to develop a prototype product for a given problem area, e.g. a mobile barbecue. Later on in their studies, they learn how to use design thinking methods for early prototyping in the fab lab. Many students subsequently use the lab for their bachelor and master thesis projects when developing prototypes, e.g. a student developed a pair of remotely coupled mobile robots. Similar developments can be observed in other study engineering programs.

5 CONCLUSION

In summary, the establishment of a fab lab at our university has proven to significantly contribute to university-industry cooperation in regional innovation. Due to the early

involvement of industry partners and students, the fab lab is now a platform where industrial firms can meet and work together with engineering students. Different activities during the last 16 months of operation have led to intensifying and expanding exchange and collaborations between the two spheres of practice and academia. The open workshop environment in the fab lab encourages informal exchange and eases access to technical equipment, both for industrial research and development and practical engineering education in the region.

Major learnings are that (1) early involvement of industry, students, study program managers and research-focused institutes is vital to develop adequate service offerings, (2) regular social events and outreach are necessary to develop a critical mass of users, and (3) inclusion of the fab lab in curricula must be given, ideally in early semesters, to make students familiar with it and therefore lower barriers for using it. The latter learning was not addressed properly at the beginning of the project, especially as curricular changes take quite a long time and internal procedures to take effect. In the future, we plan to develop metrics to quantitatively measure the impact of the fab lab on engineering education. We plan to measure both the perceived impact in the short term and the impact on innovative activity in the long term.

Given very positive experiences in the industrial engineering study programs, we plan to intensify and encourage the use of the fab lab as a collaboration and education platform for further study programs at our university. Our service offerings will also be further expanded, as we work on introducing remote support via app until the end of the year.

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