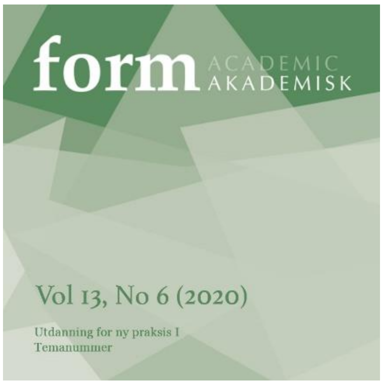

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Designing an Interdisciplinary Course in a Makerspace

Towards collaborative creativity for a sustainable society

ABSTRACT
The study explored how to develop an elective, interdisciplinary course in a makerspace. The study highlighted the potentials and pitfalls in the transitional space between institutionalised and research-based higher education in relation to the free maker movement. The identified success criteria to set up an elective, interdisciplinary course in a makerspace were connected to the following central concepts: problem, practice, product, bodies of knowledge, critique, scientific discourse, methods, earlier knowledge, personal experience and organisational processes. The study showed how the makerspace

elective course can contribute positively to student life by strengthening inclusion, a feeling of belonging, study enjoyment and interdisciplinarity skills in a professional setting. These qualities form a value-based conceptual framework for student active learning that can enable creativity and collaboration, which are essential twenty-first-century skills for a more sustainable society.

Keywords:
arena development, boundary object, interdisciplinary, makerspace, motivation

INTRODUCTION: A NEED FOR RESEARCH-BASED COLLABORATION ACROSS DISCIPLINES

In the current study, an elective, interdisciplinary course at the OsloMet Makerspace was explored as a 'boundary object', by analysing the creation of a course in a makerspace context. Such a context opens new possibilities in terms of the premises, organisation and systems that exist around the establishment of an elective, interdisciplinary course. The first definition of a 'boundary object' was introduced by Star and Griesemer: 'Boundary objects are both adaptable to different viewpoints and robust enough to maintain identity across them' (1989, p. 387). This was based on an example of the collaborative elements found in a zoological museum and the large variety of interest from a diversity of stakeholders around these elements, interest spanning from researchers and professionals to amateurs. Star and Griesemer proposed four types of boundary objects: *repositories, ideal type, coincident boundaries and standardised forms* (1989, p. 410).

They described the first category, *repositories,* as 'piles' of objects, such as collections in a library or museum. Second, the *ideal type,* can be exemplified with a diagram or an atlas and is a means of communicating and cooperating symbolically; this can work as a 'good enough' road map for all parties. An example of an ideal type is the species, such as a specific type of an animal. Third, *coincident boundaries* were described using the example of the creation of California and how the maps of California differ—the maps created by amateur collectors and those by the professional biologists were different—but even though this is the case, they still have something in common. Finally, *the standardised form* was described as a method of common communication across dispersed work groups, such as standardised indexes. Although all these categories have vague borders, there is something in the content that makes a variety of different groups interested in it because of a diversity of motivations. Star and Griesemer further exemplified that people who inhabit more than one social world—marginal people—face an analogous situation (1989, p. 411), which can be seen similar to how a student from one profession meeting a group of students from another profession, and where it can be a challenge to keep a professional identity as well as collaborating with an unknown culture of professionals.

There are challenges when research traditions collide in practical projects and interdisciplinary courses at a university; therefore, to enhance the understanding of research-based interdisciplinary collaboration, the concept of the 'boundary object' can be used as a suitable perspective to consider the values of an elective interdisciplinary course.

BACKGROUND: NEW WAYS OF INTERDISCIPLINARY COLLABORATION

The current study touches on the mentioned areas by analysing the development of an interdisciplinary elective course for a makerspace context in a university. A makerspace was established at a university where the present study appeared, and it was very successful and popular among students. However, the physical learning environment was hidden in an anonymous classroom, and in 2018, the university wanted to expand the project by establishing a new physical space on the ground floor with windows exposed to the street. The interdisciplinary elective course was developed from 2018–2020.

The course was designed to fit diverse motivations from students in a multidisciplinary university. Indeed, multidisciplinarity is integral to any makerspace. The target group for this makerspace was approximately 3,200 students at the Faculty of Technology, Art and Design. There are 12 bachelor's programmes, five master's programmes and several year units and individual subjects.

The students involved include civil engineers who calculate the strength of bridges, drama students who specialise in theatre in teaching, IT students who develop C++ code and designers with design process creativity. The people, methods, traditions, forms of work, teaching and assessment, background and future were all different. These represent a variety of different groups interested in a makerspace, each group showing a variety of motivations, similar to how Star and Griesemer exemplified that people inhabit more than one social world (1989, p. 411).

The makerspace and the new elective course's necessity were that it had value in bringing together students from such different educations. There were problems that were thought of and solved by the group of people planning the course, such as including sustainability goals. There was a goal to aim for both societal relevance and educational relevance through the course that was to be developed in the makerspace.

There was a need to develop such a course in practice and to study the process because although the makerspace movement has made its entry into many arenas in higher education (Hirscher et al., 2019; Kajamaa & Kumpulainen, 2019; Pettersen et al., 2019; Valente & Blikstein, 2019), some makerspaces are more formalised, while others are more informal. There was an educational need to study how to formalise the course while keeping intact the students' intrinsic motivation in interdisciplinary learning in a university setting, and the development of a course in the transitional space between institutionalised and research-based higher education and the free maker movement. A teacher in this learning arena would need to be aware of the potentials and pitfalls in such a context where a student from one profession meets a group of students from other professions.

Learning experiences from the process of establishing such an interdisciplinary course can be useful for others with similar needs, especially in higher education. The study further has relevance in a wider perspective, such as for primary school, curriculum thinking and other contexts that aim for active student learning and interdisciplinary collaboration. The boundary object concept, which originates from the social sciences, was chosen as a part of a theoretical framework because the concept has been shown to have a value for collaboration that spans several other research areas, such as in engineering and mathematics (Shanahan et al., 2016), design education (Johnson et al., 2017) and in arts education for children (Frisch, 2020). A stronger focus on collaboration across these areas is needed because it contributes to solving the challenges defined in the sustainability goals. Indeed, the complex issues of a sustainable society need an innovative and multidisciplinary approach.

By design, a makerspace is a space where multiple disciplines, arts and professions come together. More than a workshop, in a makerspace, ways of thinking, doing and learning come together. The makerspace movement emphasises 'learning-by-doing', sharing of knowledge and solving problems. Several researchers have emphasised learning-by-doing, including Dewey (1958); he emphasised that learning through action is an aesthetic experience. This can be seen as part of a constructivist tradition, where the student's own experience is emphasised as a central pedagogical method. Other researchers have emphasised personal experience but believe that interaction with others is important in creating shared experiences (Vygotskij et al., 1980): here, the pedagogical idea is to construct relevant knowledge together. Vygotskij et al. (1980) introduced the concept of the 'zone of proximal development', facilitating just enough learning processes for the individual to independently be able to progress further without detailed instruction, hence allowing the student to develop a feeling of mastery that creates both identity and motivation, a pedagogical approach that has been developed into design teaching and other learning contexts (Lyche, Berg & Andreassen, 2018; Wennergren & Rönnerman, 2006).

Students with a background in either technology or aesthetic subjects will work together in this elective course, so it can be a challenge to identify the various zones of proximal development. It will be a meeting between professions with potentially very different experiences and different views on knowledge. Putting students with different backgrounds in a group is a challenge that can turn into an advantage. Such interdisciplinary groups require a flexible timeline, where the process develops differently in each group, depending on who participates. The students who participate in the course can learn from another and thus they can draw knowledge from anthropology in social sciences to understand users in design methodology, and they can get knowledge from physicists' tests from engineering students. The synthesis between these takes place in practice, and knowledge domains come together in the practical activity (Molander & Terum, 2008). This ability to acquire relevant knowledge and collaborate is a learning outcome in most professions and is especially relevant here where the students will learn from each other, with experiences from both human science traditions and natural science traditions.

In the human science traditions, the view of knowledge is often characterised by ways of interpreting and understanding the world, such as in hermeneutics (Gadamer, 1979) or action research where social processes for a system change is a goal (Lewin, 1997).

In the natural sciences (e.g., physics, biology and chemistry), there are other ideals. Karl Popper's *Logik der Forschung* (1935) should be mentioned, and the hypothetico-deductive method (Godfrey-Smith, 2003) is considered by many to be the basic method in modern science. In engineering, selected topics from the natural sciences are included, such as knowledge of materials and the study of their properties, numerical and analytical methods to solve equations, techniques to optimise production processes and the ability to create powerful yet simple models that capture the important features of physical systems.

Makerspaces are relatively new phenomena, but these established theoretical perspectives on learning have been relevant for establishing an elective course. These theories can be seen as epistemological premises for artefacts and practices. The strategy in an interdisciplinary course with a makerspace was to facilitate these views of knowledge can come together.

A makerspace incorporates student active learning. Through activities, the makerspace is a place where the university becomes an arena for a variety of stakeholders, where learning, business and society converge. Hence, the research question in the current study was as follows: How can a makerspace elective course be developed to contribute to new ways of interdisciplinary collaboration in higher education?

METHOD: CASE STUDY OF HOW TO DEVELOP AN ELECTIVE COURSE IN MAKERSPACE

The chosen method was action research because the project was about system change with the involved coresearchers (McNiff, 2010). In this case, there was a possibility to change the education system by establishing a new elective course, and many participants and decision makers were available as coresearchers. Also, a case study was a suitable approach because the research question was aimed at an empirical inquiry to investigate a contemporary phenomenon in depth and within its real-life context, where the boundaries between the phenomenon and context were not clearly evident (Yin, 2018). As a theoretical framework, the propositions of success criteria (Westerveld, 2003, p. 412) were indicated and explored, including the result areas related to Westerweld's proposition of finding project success criteria combined with organisational critical success factors. Thus, Westerweld's 'project excellence model' should include project results, such as the development and implementation of the course and appreciation of the client, which would entail student inclusion. 'The project excellence model' should further include the type of appreciation by project personnel and users, as well as the contracting partners and stakeholders, which in the making of a course in makerspace would include both students, teachers and possible external collaborators. The 'project excellence model' from Westerveld also includes descriptions of the organisational areas. such as leadership and team, policy and strategy, stakeholder management, resources, contracting and project management.

The evidence for the case study came from six sources: documents, archival records, interviews, direct observation, participant observation and physical artefacts. The strategy for identifying patterns in the findings from a single case study was performed in relation to other relevant studies and theories and through pattern matching (Yin, 2018) of a procedure in an organisation.

The current study was funded by the university and was a part of the strategic aims of the faculty's lighthouse project 'Didactics and Education in Technology and Design'. It was also funded by Diku (the Norwegian Agency for International Cooperation and Quality Enhancement in Higher Education) through a project on 'student active learning processes', which constitutes a preliminary

organisational success factor. Further, the research was initiated and realised by faculty members who were involved in creating, planning and teaching in the course. The aim of the course was to engage and connect students who have advanced competence from various fields. The course was elective. One aim of the course was to investigate how the course could contribute to sustainability goals through interdisciplinary competence (Nielsen, 2010; Lewin, 1997), such as developing competence of collaboration, cocreation and creativity, here by adding preliminary project success criteria. This was supported by studies of how design can contribute to sustainability (Skjerven & Reitan, 2017). With participants from different disciplines, it was necessary to include a variety of worldviews on what was seen as suitable knowledge, epistemological preferences and traditions on professional knowledge, along with how the participants' fore-meanings influenced their horizon of understanding (Gadamer, 1979), which constituted another preliminary project success criterion. Hence, the chosen empirical results reflected the coresearchers' variety of fore-meanings developed from their various experiences of education at the master's and PhD levels, as well as from their practices.

In the present study, the aim was to analyse the documentation to identify some success criteria that might be interesting for others; these included the most significant concepts, phenomena and decision-making situations that led to the establishment of the course. The preliminary success criteria—were based on the process of establishing a course including a societal problem of sustainability, methods of interdisciplinarity, students' inner motivation and the formal establishment in an organisation. Through an analysis of concept mapping (Maxwell, 2005) of some relevant initial success criteria based on experiences and theory, in relation to the empirical evidence a set of success criteria can be found.

A preliminary project success criterion related to societal challenges and sustainability was experiences from the course makers that the makerspace can make people aware of how easy and sensible it is to repair and reuse. Another preliminary success criterion about course relevance was related to wicked problems (Edmondson, 2016). Wicked problems in design thinking are ill-defined problems with multiple dependencies and solutions and where any change to one part of the problem or solution may trigger a change in a different part—possibly even creating a new problem. In business, multidisciplinary teams are often used as a means to handle wicked problems (Edmondson, 2016). This was chosen as a preliminary success criterion because it would be helpful to facilitate collaboration between students from seemingly unrelated disciplines and let the students experience first-hand the value of multidisciplinary collaboration by solving complex challenges such as sustainable production or other wicked problems. When finding a solution to a wicked problem, it will often be hard to find any 'correct' answer, but a solution that may have a positive effect and that can be relevant can be accepted as a success. The next proposition of a project success criterion was to design the elective course in such a way that it would support and trigger the intrinsic motivation (Ryan & Deci, 2000) of the students so that they could better identify their own competence by collaborating with fellow students with backgrounds from seemingly unrelated disciplines. Thus, the students should actively monitor the learning outcome of the collaboration and use the makerspace as a learning arena—a sort of mirror to see themselves through others. The students should be able to show their own knowledge, strengths and limitations through collaboration with fellow students from other subject areas. The next preliminary organisational success factor was related to the formal establishment of the course. The proposition was that it is partly contradictory to establish a makerspace in a university environment (Pettersen et al. 2019), integrate it into programmes and courses and keep the free maker movement spirit. This was a relevant perspective to identify for the decision makers who could change the system and formally establish the course and who experienced the challenges of this first-hand, such as getting financial and professional support; an issue relates to this was expanding the understanding of the free maker movement among faculty and administration, not the least to get access to suitable premises for creating a physical learning environment on campus with the necessary tools and technology. Related to these preliminary success criteria are the sources of evidence (Yin, 2018, p. 100): documents that show the beginning of the course, such as initiatives from the faculty management and that the project was financed.

In a study of interdisciplinary collaboration from information science as described through the perspective of boundary objects, concrete examples include i) informational artefacts; ii) their related practices; and iii) the epistemological premises of artefacts, practices and their intersections (Huvila et al., 2017). Huvila et al. (2017) claimed that boundary objects negotiate meaning and help to understand and articulate the connections and disconnections between communities, cultures and information infrastructures. The empirical data in the current study exemplify a variety of informational artefacts from a makerspace, a variety of practices related to the artefacts and different concepts and understandings from a variety of professions.

Examples of these have come from the various sources of documentation, including a student report; here, a group of volunteer students wrote the first draft of the course description and a report documenting their work. Other sources included documents that were publicly available, TV and radio news and newspaper articles about the physical building where the makerspace was situated. Another source was the archival records: the application to Diku, Norwegian Agency for International Cooperation and Quality Enhancement in Higher Education and previous European Project Semester (EPS) reports. The EPS reports were chosen because it was a project where students quickly reached a deep level of collaboration, similar to how the aim was in starting to cocreate something tangible in the makerspace. The study also included interviews: a user survey with 51 responses from students where the goal was to investigate the important parts of an elective course. Furthermore, participant observation was used: documentation of physical learning environments, classrooms, institutional decisions and internal/external strategy funds. Another source of information was the physical artefacts, such as objects made by students, visors made for the COVID-19 pandemic crisis and products made for the student exhibition space.

The documentation from the sources is presented in a narrative of the process, as recommended in case study research where the relationship between evidence and theory is coherent (Yin, 2018, p. 100). Thus, the selection of data is based on the research question, the propositions formulated as preliminary project success criteria and organisational success factors and in relation to the process of establishing an elective course, explained in a way that includes the societal problem of sustainability, methods of interdisciplinarity, inner motivation and formal establishment.

RESULTS: EPISTEMOLOGICAL CONCEPTS, ARTEFACTS AND PRACTICES IN A MAKERSPACE

The findings from the current study describe a diversity of issues found in designing an elective, interdisciplinary course in makerspace.

Coincident boundaries: A pilot course developed by a student group

A group of students who used the makerspace quite often and who were from different study fields within the faculty were commissioned to makerspace elective course and to give their perspectives on how to solve the assignment from the Diku project. In the introduction of the report, they wrote, ‘The goal of the elective course is for students to gain practical experiences that prepare them for work life, and challenges related to collaboration, concept development and prototyping’. By analysing the different fields of study at the faculty and their programme plans, the students defined common topics that they thought were relevant for all: entrepreneurship, design, visualisation, creativity, prototyping, project and process development.

Further, they wrote, ‘As a result of these findings, we arranged a brainstorming session, and concluded that the structure of the elective course should be based on project work, inspired by the maker movement’s “Hackathon”, which are longer projects where you develop a product or a prototype and solve a specific problem’. The students also conducted a survey to get insights into areas of interest in the various fields of study at the faculty and what they would be interested in learning more about in the elective course. In relation to students’ motivation for participating in the elective course, they wrote, ‘When asked which three areas engage students to participate, most answered that it is “personal interests” that is most important, followed by “theme” and “preparations for desired field of work”’.

The students also pointed out that most student participants in the survey said they would prefer to work practically, meaning that it would be highly relevant to use the makerspace's workshops and tools to develop products, prototypes and ideas as part of the elective course. Furthermore, they wrote the following:

> The students generally answer that the first impression of the course seems exciting, and that it appears interesting even before the course has been published. It is possible that many good ideas can be generated when collaborating across disciplines, from which students can learn a lot. They also get to try out interdisciplinary collaborations, which resembles the reality of work life.

It was reported that lecturers were generally positive regarding their first impression of the subject and responded much like the students. The student participants in the survey also believed that the course could be of great value to them personally, and by gaining broader knowledge in this area, it would also have a positive effect on how they would cope with their studies in general. One student emphasised that the course could also provide new ways of solving things cheaply and efficiently. The lecturers believed that the course was future oriented and would provide competence that students would benefit from later in their work life. The students concluded that they wanted the elective course to focus on topics that seem relevant to both technology students and students in aesthetics and design education. Sustainability and global challenges were mentioned as examples. They also concluded that it was important that the students experienced the elective course as relevant to their own field of study and future work life.

Based on these student comments, it seemed that interdisciplinary collaboration can be both a motivation and starting point for the development of knowledge, innovation and visibility; here, there were four central issues: The first was product focus, including questions related to scale, utility value, production and product development. The second was craft focus, creating a physical product, using and developing craftsmanship and engineering and technology knowledge and experience. The third was aesthetic focus, including design, material knowledge and testing, the intrinsic value of the materials, new compositions, expression and communication and visibility. The last was a method focus, which asked the following: To what extent can the makerspace or topic be a framework for this type of project? Examples of this type of project should be a type of thinking, such as problem-solving methods where one sees interdisciplinary connections, similar to wicked problems (Edmonson, 2016).

Repositories of objects: Exhibiting collaborative prototypes

The students suggested that after a compulsory group presentation in the elective course, a maker festival should be held under the auspices of the makerspace. Here, it was desirable that the groups present their projects. Students got the opportunity to showcase their work to the outside world and could network with companies. An example of such an interdisciplinary group project was made and by a student group from product design, electronics and information technology, applied data, robotics and intelligent systems and pedagogy; this group made a visual map of the subway routes in the city in real time (Figures 1 and 2).

Figures 1 and 2: Interdisciplinary student work: a visual map of the subway routes in the city (Figure 1) showed at the mayor's visit (Figure 2). Photo by OsloMet Makerspace.

FIGURES 3 and 4: Viribus CB1: a cardboard robot made at makerspace with led lights, a loudspeaker and around 350 other elements in a variety of materials (figure 3) with poster information (figure 4). Made by Markus Steinsland. Photo by OsloMet Makerspace.

Another example of a student work from the makerspace was 'Viribus CB1' (Figures 3 and 4), a puppet/robot made by a drama student working on a master's degree. Through the makerspace, the student studied electronics, laser cutting, 3D printing and programming to build it. The student spent many hours learning this on his own in the makerspace, as well as with a lot of guidance from other students.

The students wrote further about external communication: 'The festival invites external entrepreneurs, and activities inspired by the maker movement are arranged'. The students proposed a maker festival and envisioned that a display of the student groups' work would be motivating for the process and important in terms of networking. In this way, the course would be able to expand the arena for student work and expand the makerspace in general.

In several contexts, the university as an institution had expressed the need and desire for visibility in the campus context, but also in the cityscape. Having the makerspace at street level was a part of this strategy. By exposing the building through the makerspace, the university was shown more as a 'living laboratory', and this could also include the extended structure of the university, such as showing as much as possible of the control system and the functionalities in the building. Therefore, the physical spaces of the makerspace at the university were an example of changing the learning arena from hidden and difficult accessible classrooms to a 'window exhibition' facing the street, hence being an open accessible learning arena (Figures 5 and 6). This has the potential to grow into a specific kind of arena development, where technology, art and design become one culture arena that can also become part of a cultural policy aim and artistic research (Norvalls, 2015).

FIGURE 5 and 6: Learning arena example 1: The makerspace as an exhibition window seen from the outside (Figure 5) and as an expanded learning arena seen from the inside (Figure 6). Photo by OsloMet Makerspace.

FIGURE 7 and 8: Learning arena example 2: The makerspace in media: at the 'research days' (Figure 7) and in a TV interview about visor production during COVID-19 (Figure 8). Photos by OsloMet Makerspace.

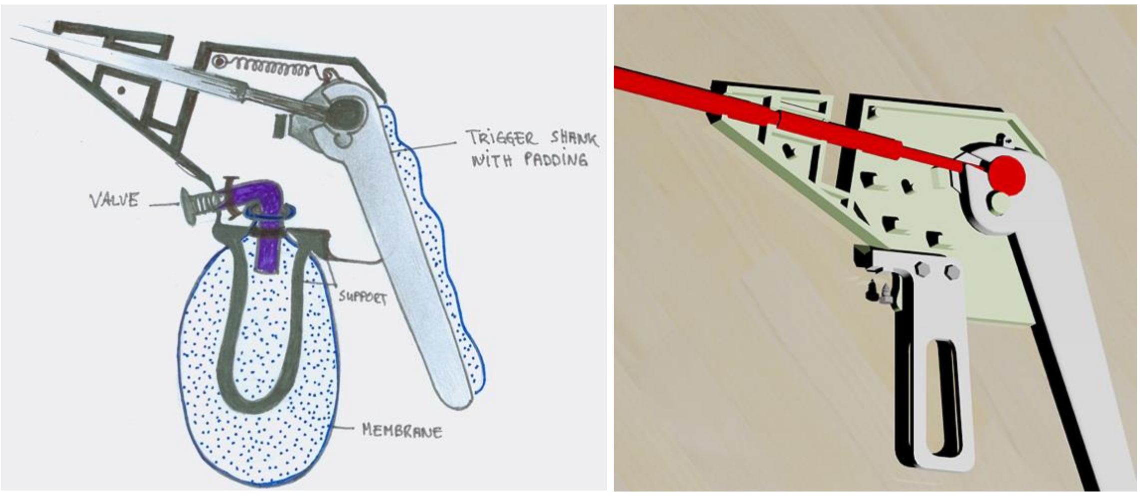
Other examples of an expanded learning arena for the makerspace were the visibility in society that came in the form of public arrangements such as 'research days' or when the makerspace was exposed in multimedia channels for its production of visors during COVID-19 (Figures 7 and 8).

Another example of a learning arena development is from Stuttgart, which shows interdisciplinary collaboration of computational design, simulation and fabrication processes in architecture in a research context. The projects are different from year to year but are often built around, for example, areas related to pavilions, such as adaptive architecture, biomimetic investigation and integrative digital design models. These are high-tech collaborative physical projects, where one goal was that the pavilion contributes to the visibility of the university. This was a collaboration between the Institute for Computational Design and Construction, the Institute of Building Structures and Structural Design and the Institute for Textile and Fibre Technologies. Another similar example from the University of Bergen was the project 'experimental wooden structures. Annual pavilions in the city centre of Bergen were large-scale combinations of engineering knowledge, craftsmanship, aesthetics and visibility led by Professor Petter Bergerud, who used the following words as a goal for the projects:

'press boundaries', 'inspire', 'engage' and 'excite'. A final example was 'The Hive', a pavilion now situated in Kew gardens, London. 'The Hive' is an art project and visual tribute to Britain's honeybees. It was a project with many layers, showing how advanced interdisciplinary collaboration work can be used to highlight a global environmental problem through design and construction. It was designed by UK-based artist Wolfgang Buttress and can be used as an inspiration and basis for interdisciplinary collaboration.

These types of projects can help to expand a mindset, culture and course understanding; this can be put in combination with the thinking in a makerspace, which should contain aesthetic values, expressions and communication found in art and design, art didactics and relational works.

This multidisciplinary field is potentially also a field of stressful tension that should be handled by students and supervisors in an elective course, mirroring the established research traditions in an institution, traditions that can span from art installations, design constructions, ecological politics, material structure and engineering art.



FIGURES 9 and 10. Iterative process of prototyping medical technology concepts: Hand drawing (Figure 9) and digital drawing (Figure 10) for the adaptive handle for laparoscopic instruments. Photos by Evin Güler.

An example of prototyping in a smaller-scale arena development in connection with makerspace activities can be taken from product development (Güler, 2013). In this master's study from 2013 by one of the co-authors, the goal was to improve an existing handle of a medical instrument for minimally invasive surgery. The focus was to map phenomena around the product, thus starting a product development process through 'design thinking': What is the problem, why is it important, how can it be made better, what are the available solutions and how can a new solution be developed? The study also involved testing of different prototypes in an iterative process (Figures 9 and 10). The tools used were mostly 3D printing and 3D design. Models were sent to NTNU workshops, where a technician helped with the actual 3D printing. The product was an 'adaptive handle', which adapted to the user's hand and was inspired by 'robotic hands'. The idea was to shape the handle using a bag with small beads that created a flexible and loose structure. When the user gripped the handle, the air inside the bag was sucked out from it, and the resulting shape conformed perfectly to the user's hand. This way, health professionals could avoid getting pressure injuries from using stiff and generic instruments. The name of the product was 'adaptive handle for laparoscopic instruments' (Güler, 2013).

Such concrete examples can be used to develop theory and practice for participants in the course. For an engineer, especially in medical technology where products are created for humans, such a study can help them think more holistically. In a makerspace, people often work with someone from a different background, and they have the opportunity to utilise others' professional knowledge and approach to product development. Thus, the participants will be encouraged to think more holistically in terms of production, technology, construction, user experience and the significance of the product beyond just the technical quality or beyond only the aesthetic quality.

In the informal contexts of the makerspace, students can get a lot of attention, and discussions arise easily as they begin to iterate on the solutions together. One danger in this is that students can become only a generalist, losing focus on their own field of study. The traditional role of an engineer, for example, is seen by many employers first and foremost as technical, and it is required that the engineer know their field well. Still, such prototyping is relevant, for example, in fluid and construction mechanics, where some students took part in a competition in which they had to 3D design and print a bridge of 5 grams that could carry as much weight as possible. Concerning prototype development, the makerspace reduced the time between the concrete idea and finished product, which gave the students the opportunity to test their designs along the way. Lowering the threshold for prototype development can help students detect problems in the design that they have not thought of. This has relevance for professional practices because students get experience in handling opportunities and limitations that very likely can happen in work on a larger scale.

One example of this is the collaboration processes in product development and design methodology that have a value when transferred to many other areas, such as enhancing the user needs. Although a design process is often a user-centric approach, it also often takes into account decision makers in several stages, such as managers, stakeholders and owners. Considering materials and aesthetics, concrete products can be used to strengthen communication both in the process and product (Berg, 2018). This creates an experience that gives a gentle touch to interdisciplinary collaboration, where everyone contributes with their specific professional area to a common goal and where it is not intended for everyone to do the same thing; it is this complementary competence that can happen in an interplay that is the main point.

Ideal type: Do it yourself in a makerspace

One premise of good practice was based on the idea that the effect of working in a makerspace can make people more collectively aware of how easy and sensible it is to repair and reuse. One physiological argument for this can be found at 'Tetris effect', which showed that experimental subjects who played Tetris for a total of seven hours—distributed along three consecutive days—experienced intrusive visual images of the game when falling asleep (Stickgold et al., 2000). The study shows that when exposed to a certain pattern recurrently, some associated imagery is bound to stay. More interestingly, this does not require intentionality because the subjects reported not being able to prevent these thoughts. In the same way, if one is regularly exposed to the idea of repairing instead of replacing, one may be likely to transfer this approach to other areas.

By repairing and making things at the local level as in a makerspace, in the long run, each person working in that space can help contribute to more sustainable behaviour. This local and individual perspective that can be enhanced in makerspaces is about making products, which is increasingly important because the consumption society has become very complex and because many products have such a short lifespan. This again contributes to the throwaway culture. The design researchers Lutnæs and Fallingen (2017) pointed out, for example, that in a sweater that a pupil wears today, there usually is a global patchwork of production processes, where they have lost a number of experiences connected to the production process. Skills and knowledge needed in the production of a sweater have been forgotten in contrast to earlier times when pupils were more familiar with local production processes; someone they knew would make sweaters from local wool, where they could follow the production process all the way, often in a more sustainable process (Lutnæs & Fallingen, 2017). Such examples of products can be seen from a critical perspective as informational artefacts. Every single product can be understood as made by many people with a variety of motivations. Many people today do not even think about repairing products but have become part of a system that is about use, consumption and disposal. People are incentivised to buy something new, which means that throwing away has become the new normal.

By experiencing production processes in a makerspace, students can go from being pure consumers to becoming creators. Instead of just buying things, students can sometimes spend a few minutes making or repairing the items themselves. These products may be practical things for the home, such as pegs for hanging jackets in the hallway, which is something the students can make on their own instead of buying it in the store. By getting inspiration from shops and online sharing communities like Thingiverse and Instructables, where students can learn something at the same time, superficial images of things are connected to an understanding of the construction of that item, a kind of 'walk the talk' practical approach that can shape new habits and ways of thinking. By learning to fix things that are damaged, opportunities to learn about materials and their properties become available. This contributes to the value of being able to make something and learn at the same time, where the feeling of mastering a craftmanship can be seen as a reward for skill and commitment (Sennett, 2008).

Developing knowledge about making and repairing things is general competence on sustainable ways of acting that can have transfer value between several areas, from advanced electronics to simple functional items in the home.

Making and critical reflection

The makerspace has been criticised for being too focused on play and fun, where students have made things without a social benefit; hence, there have been calls for more studies on how the urge to explore in a makerspace can contribute to new ways of thinking education (Pettersen et al., 2019). Here, experiences from the EPS were relevant in the planning of the course. In this one-semester programme, the makerspace was not mandatory, but many student groups chose to use it because they saw the benefits in producing physical artefacts as part of their projects. When creating artefacts, supervisors observed that new ways of thinking about processes and production manifested. Students without previous experience learned to code simple programmes or experienced the sturdiness of composite wood. The way students mentioned this in their final presentations in the EPS indicated that this could be relevant for other students as well. Additionally, EPS students often commented on this experience in reflective form, such as in how they surprised themselves by learning something they had not previously considered, thereby learning something about their own abilities as well.

Similarly, related to the subject mentioned above, the makerspace project course gave students a project brief that the students had to scope down and adjust. Therefore, they were not given absolute freedom. At the same time, the project briefs were an ideal type described in the boundary object concept, but they were wide enough to allow for student autonomy and a lot of 'play and fun'. Whether this leads to new educational practice and pedagogical thinking depends on the level of learning and reflection and how theory and previous knowledge inform the actions within the makerspace.

Ideal type of making processes and simulating self-organised teams

Research-based approaches can also be key issues in a makerspace and in an elective course because students and teachers have the opportunity to influence where the process starts and ends. Regardless of where in the production process the students are, different types of processes can lead to learning about creating lasting values that are linked to sustainability goals. In the makerspace, a variety of different contexts are discussed in which the learning process can be put. For example, the development and testing of materials, technology, products and techniques may not be sustainable in itself, but when put into a larger or different context, they can have many qualities that strengthen sustainability because small parts can be seen as a piece of a bigger picture. Bits and parts of work processes therefore can be seen as important learning outcomes in a course. This is especially relevant in thinking about the epistemological premises in developing a makerspace course because many see social processes as something fundamental in the 'maker movement', for example, through problem-based learning.

This is an aspect of the epistemological premises for artefacts and practices that can be found in learning from practice through case study methods (Yin, 2018), where a deductive and inductive approach is combined with methods that explore a theory or methods that explore practice.

Any learning process can be organised in various ways, such as the organisation in supervision groups, having many or few formal requirements and focusing on a product rather than a written report for examination. To organise the learning activities in the course, the students can plan how to simulate self-organised teams, as they will often encounter at work. A kick-off (first meeting) will be followed by a progress report (second meeting) and a final delivery (fourth meeting with exam). The third meeting will include focusing on design thinking as a method. Apart from this, priority in general will be given to mentoring rather than supervision, optional mini courses on maker processes and tools rather than theory classes, and the exam was based entirely on the final product. With this set-up, the students' experiences of self-organising and accepting control was set up as a learning outcome.

Students in this elective course in the makerspace were expected to develop a shared understanding and to 'translate' their discipline's knowledge for the rest of the group. This knowledge that had been learned in their own studies may often be tacit knowledge they are rarely asked to verbalise. Experiences from the course makers from other subjects was that of combining engineering students and design students encourages them to not just articulate tacit knowledge, but to rethink and express knowledge that they were unaware was profession-specific knowledge.

In this course, there were planned non-compulsory classes on project management methods, such as sequential waterfall model methods, more organic agile project management and other combinations. However, there was no planned form of assessment of the groups' self-management skills or any classes given on group work. Yet some scaffolding was called for. Rather than classes, 'mentor's meetings' were planned to check in on the students and their progress as a group.

Coincident boundaries: The organisational challenge of multieducational subjects

Organisational systems such as room booking, and time schedules are a challenge in large universities. An interdisciplinary subject using workshops—which the students decide themselves when to use—posed several challenges. The obvious one was time: an interdisciplinary subject such as this can be almost impossible to schedule into a normal working day without at least one student colliding the schedule with another course. The second challenge was the unpredictability of the development in a system where space must be reserved: the uncertain progress of such projects—through several iterations—could not be scheduled into the makerspace far in advance.

If a makerspace course is part of the education, the course can be planned in collaboration with other courses in the same field. With students from five different areas of study, the course developers chose to minimise the number of compulsory teaching hours and maximise the students' availability to tutoring throughout the semester. The hours the makerspace was open, and flexibility formed a sort of coincident boundary for the participants. An accessible makerspace with long operating hours and good capacity was a must for giving students as much freedom as possible. This solution was supported by experiences from teacher education in arts and crafts, which showed that students who are in practice placements shape their own practices, but they also received guidance from the teacher's collaborators: practice teachers at school. This was governed in relation to curriculum work and the system they encountered outside, not by the university's working methods. There was a need for thinking like this in the makerspace course.

However, what formal contexts were needed? In what may seem like complex systems such as schedules and room bookings, in a process where physical artefacts are to be created, it becomes more a question of what qualities are in the room and of thinking of a makerspace as a physical learning arena that opens new possibilities—that have affordances—in terms of premises, coordination and systems. Often, systems such as room bookings and lecture structure are traditionally based on a teaching mindset, an educational ideology where students should sit quietly to be taught, not be active. It is a challenge to gather people to teach in physically equipped laboratories, and in the same way, it is a challenge to get a free maker spirit in traditional classrooms. Thus, the theory-based system is reflected in the room booking system itself and in the assessment criteria. When a physical artefact or product is to be created, a report is often also requested as documentation rather than a physical or oral description, even if both parts formally have been approved as examination requirements in Norway.

All these different traditions and motivations influenced the course description and the learning outcome descriptions.

Standardised forms: The learning outcomes in the course

Part of institutionalising the 'maker spirit' was to describe it in the concrete and precise language of a course description that the university students would be accustomed to. This was a challenge. In part, one encounters the general problem of course descriptions: Who is the target audience? Who should the course be written for? These are future students, current students and others with some professional knowledge who may have set out to read the course description. Especially for this course, it was not possible to describe the learning outcome to the level of detail needed in some study programmes. For many engineers, for example, Newton's laws will appear under both knowledge and skills in one subject or another. This was not the case here. It was more challenging describing in advance the theories and methods that a given group of students will use because they will probably need different theories depending on the various projects they choose.

Therefore, the focus was more on generic knowledge and general competence, such as 'The student has knowledge of the appropriate implementation of project work and problem solving in groups' or 'The student can communicate their own specialised subject knowledge to an interdisciplinary group'. Generic learning outcome descriptions of this type can sometimes appear quite cryptic. Because this was an elective course, a more comprehensive introduction than usual was needed. The introduction explained a project's central role in the course, and examples of overarching themes for the project were mentioned. It was made clear that the students would work in interdisciplinary groups and have access to equipment in the makerspace and in various labs. The course description included the number of meeting days and short descriptions about their content.

The final learning outcome descriptions in the course were approved by the education committee and were offered to the students at the start of autumn 2020. After completing the design of the course, the students' knowledge, skills and general competence were described in the programme plan. In knowledge it was described that within a superior task the student has knowledge of the appropriate implementation of project work and problem solving in groups. Further it was described that the student has insight into product development, from idea to prototype or finished product. The student knows the uses of the tools found in makerspace.

Skills were further described as the student being able to carry out product development from idea to prototype for a physical or digital product. The student could use the selected tools in the makerspace to create the prototypes. Students could regulate their own progress in project implementation, and they could communicate their own specialised subject knowledge to an interdisciplinary group. In general competence, the learning outcomes were that the student could select relevant materials, methods and tools. The student could work in interdisciplinary groups and see interdisciplinary contexts. The student needed to master methods for design and implementation of projects. The student can convey the problem, idea, and product to others.

The assessment method in the course was described in the course description: at a final presentation in the group, the students were assessed as passed/failed. Both grade scale and assessment expression were discussed with the student group that developed the course. In the feedback from the students' initial report there was no unanimous group that landed on this assessment method. In the pilot stages of development, this was the most debated part of the course.

DISCUSSION: SUCCESS CRITERIA IN MAKING AN INTERDISCIPLINARY COURSE FOR A MAKERSPACE

The issues that emerged in the process through concept mapping (Maxwell, 2005) was made into a visual presentation of the most important success criteria (Figure 11). These were based on the theoretical framework that made the groundwork for some preliminary success criteria for establishing an elective course related to the makerspace. The documentation from practice was selected based on the theoretical model of boundary objects, and the four subcategories of repositories, ideal type, coincident boundaries and standardised forms (Star & Griesemer, 1989, p. 410) and based on project success criteria and organisational success factors (Westerveld, 2003).

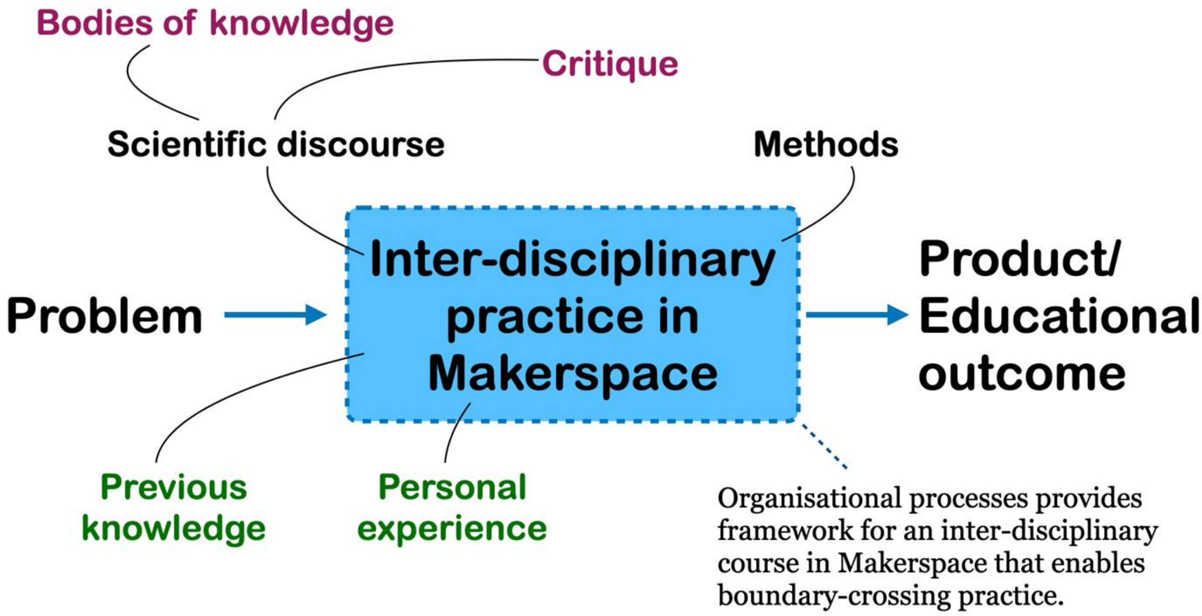


Figure 11. The identified success criteria to set up an elective course in a makerspace. Design by Sandtrø.

Taken together, these were the 10 success criteria for found for establishing this course: 1) problem, 2) practice, 3) product, 4) bodies of knowledge, 5) critique, 6) scientific discourse, 7) methods, 8) previous knowledge, 9) personal experience and 10) organisational processes of makerspace (Figure 11). There were three main project success criteria: 1) problem, 2) interdisciplinary practice in the makerspace and 3) product/educational outcome. 1) The problem which each student group developed was narrow enough to be achievable yet wide enough to allow the students agency when they narrowed down and decided how to solve it. 2) The interdisciplinary practice in the makerspace was arranged and presented in a form that allowed the students to draw on their own knowledge and introduce new methods for coproduction and interdisciplinary problem solving. Sustainability was an aspect of the need for interdisciplinary collaboration to solve a problem and was integral to the methodology of the makerspace. The practice in the makerspace included both the technical equipment and expanded learning space that emerged from the makerspace, such as exhibitions, media practice and window exhibitions on site, which can all be seen as a form of arena development, forming coincident boundaries for a variety of participants. The criteria for an acceptable product, including the educational outcome and project success criteria, 3) were defined and communicated so that the students knew the expectations of them. Further, some criteria for success were identified, and one was 4) bodies of knowledge, in which the course was established using input from a diverse field of disciplines. Both the choice and presentation of problems and theories and literature represented a range of different epistemological traditions or several bodies of knowledge. 5) Critique: The literature presents some critique of the makerspace movement, too, and the lecturers presented diverging views on project work, design thinking and critical thinking on consumption and production. 6) Scientific discourse: Taken together, the choice of a critique was made to help students grasp the current scientific discourse. 7) Methods: The methods were introduced explicitly, with a workshop on design sprints and mini courses on 3D printing. This was also done implicitly because expectations of diverse methodological traditions and choices were embedded in the problem each group chose, and this influenced the expectations for the final product. 8) Previous knowledge: In addition, thought was given to the individual student's previous knowledge and personal experience. Previous knowledge was possible to predict in the recruitment process because the course recruited from a limited number of areas of study. 9) Personal experience: The personal experience of any student was challenging, yet some assumptions may be pertinent. First, students who chose to take this course were likely to be motivated by practical work, be positive to group work and know the makerspace from before. 10) Organisational processes: The last criterion for success was the organisational context of the makerspace itself. True interdisciplinary work would demand more than just students from different disciplines dividing work and assembling a final product. We needed the organisational processes in and around the makerspace—both funding and developing a physical space and encouraging such a way of work—to make coproduction the logical choice for students.

One of the premises for the course was to learn from experiences in a different course—EPS. Based on this, the problem was introduced, and the students were asked to imagine at least three different solutions, with time set aside for thinking about user needs, context and stakeholders' expectations. Here, materials, aesthetics and physical objects appeared to stimulate discourse and collaboration.

As a project will progress, the students will be challenged to address or reflect on the implied use and user in the project brief, as well as the stakeholders' expectations. The projects selected for the students will require some reflection on their previous knowledge from engineering or design. All this ought to become acutely relevant as the prototype is manufactured and the students will prepare a final presentation.

The makerspace itself will be staffed with employees and student assistants with know-how about materials, tools and construction techniques. The head of the makerspace will provid skills within design thinking as well. The makerspace had optional courses for the students of this subject, where skills or processes that were particularly relevant could be learned. The makerspace was much more than a space with tools: it was a source of knowledge and guidance as well. In the EPS, the makerspace worked as a community, with students assisting each other. However, even if student-to-student mentoring does not happen, the makerspace can accommodate the goal of bridging the gaps between students' different expertise, the informal learning-by-doing by coproducing a prototype and the formalised demands of a 10 ECTS university subject.

Grimen (2008) pointed out that a characteristic of professional studies is that the various knowledge domains come together in practical application. By contextualising and situating a problem and designing a solution, the student must draw on a whole range of different disciplines and methodological approaches. Another aspect of the success criteria in the organisational development was that the documentation showed how it was possible to transform lessons from a classic set of one lecture per week for one semester and compress this into four sessions, enabling a high degree of student activities.

Through action research, the goal of the present study was a system change at several levels. At the micro level, where the new study module was a result of a system change, several levels of system change were also highlighted, both theoretically in the identification of epistemologically based motivations and in practice through the course opening up to different practices and different types of artefacts; here, the course can also be thought of as selected stages in a process that leads to the artefact.

Conclusive remarks: a meaningful collaboration

Conceptually, the course can contribute positively to a form of boundary object as an interdisciplinary elective course that contributes to student life as seen from both a professional and social perspective because it can contribute to values such as inclusion, a feeling of belonging, study enjoyment and interdisciplinarity skills. These qualities form a value-based conceptual framework, which can become a common ground for the course.

Drawing on the boundary object model visualised in the three forms of interplay—i) informational artefacts; ii) their related practices; and iii) the concepts of epistemological premises of artefacts, practices and their intersections (Huvila et al., 2017)—the current study demonstrated how the makerspace had challenges in coordinating studies and how to make it professionally relevant, but still, the course created a shared space for people with different motivations; there were coincident boundaries.

From a practice perspective of interdisciplinarity, a makerspace can contribute to developing the skill to reflect along the way and adapt procedures, moving towards the goal of becoming a reflective practitioner (Schön, 1983). This can strengthen the goals of developing knowledge and skills for the twenty-first century (Verdugo et al., 2013), especially creativity and collaboration. Such processes are needed for many 'wicked problems' in society (Edmondson, 2016). This kind of ideal type of thinking was relevant to all the participants.

A category of the boundary object can be seen as materialised in the course module itself: an elective, interdisciplinary course in a makerspace where a repository of prototypes and products emerged from interdisciplinary practice. This course, 'Interdisciplinary Project Work', can be a suitable compromise between the free maker spirit and the very standardised academic course format.

There is a need for further studies of how such formalised courses enable a university to assess both the students and the course in a more systematic way. This can be done through establishing academic quality assurance systems, which can enable continuous improvement of the course and the artefacts, concepts and practices of the makerspace. In the end, sharing and writing about a diversity of such approaches can stimulate a broad variety of pedagogical practices for interdisciplinary active student learning.

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