Towards a sustainable design-based engineering education

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Abstract

The engineering sciences were conceived at a different time, and for different priorities. One of the main problems with the engineering sciences is that design has been excluded from their teaching curriculum; hence, they lack creativity and have a narrow problem-solving focus with too much emphasis on mastering mathematical equations. Their standardization across the globe has failed to address the urgent need for designing for sustainability. In this research note, we outline what a Sustainable Design-Based Learning model/framework based on three levels of ambition, would entail: first, readjusting the engineering sciences to include design and sustainability as core elements; second, rethinking the engineering sciences to support a program with sustainability as a core value; and third, rethinking the program with Sustainable Design as its prime objective. We illustrate level of ambition one with the changes we have introduced in our program, 'Sustainable Design Engineering', at Aalborg University in Denmark. We discuss how levels 2 and 3 could be addressed in the future.

Introduction

The engineering sciences were conceived to support the scientific training and development of modern engineers, architects, and designers. Although the history of the scientific training of engineers is long and complex (Seeley, 1999), one could say that the modern curriculum of education was established in post-World War 2, and the Grinter report in the US is credited with outlining and establishing the core engineering sciences (Downey, 2005). However, following Lucena (2005) and Lucena and Leydens (2017), we argue that the conception of these fundamental courses was in response to the priorities of defense, either military or economical, of countries in confrontation and/or competition with each other. And therefore, these engineering sciences were being taught with a very stringent pedagogy that involved systematic presentation of theoretical principles to students. This was followed by an almost military-like training in mathematical problems which neither had a correct nor an incorrect answer. This historical development is not over yet. We still teach and learn technical knowledge in this way, in most learning institutions worldwide.

A consequence of this system of teaching and learning the engineering sciences is that historically, design was excluded from it (Bucciarelli, 1994; Eder, 1991, 1995; Campbell and Colbeck, 1998). Although recently, efforts have been made to include design in the teaching of fundamental engineering sciences (Bucciarelli, 1994), the fact is that many students of engineering, design and architecture must first master several technical subjects which are disconnected from their practice, before beginning to study the content of their main profession. This has led to an exclusion of talented professionals from the education process (Blickenstaff, 2005; Riley et al., 2009; Smith et al., 2014), and an artificial and unproductive dichotomy between science and design in engineering (see discussion).

The urgency of climate change, and more broadly, the sustainability agenda (Sachs et. al., 2019; Randers et. al., 2019) is at odds with the traditional engineering sciences. This has happened because the engineering sciences were conceived and defined at a time when economic growth, tightly coupled with material growth, was the main paradigm (Lucena, 2005). Nonetheless, the engineering sciences are based on sound natural sciences and hold the potential of contributing valuable knowledge and insights to engineers, architects and designers committed to sustainability. However, to be able to do so, we claim, the engineering sciences must be reconceptualized.

Several steps need to be taken with different degrees of ambition to achieve this reconceptualization. A first step could be to rethink each engineering science and reformulate it for sustainability, without touching the administrative and organizational fabric of educational programs, because many engineering sciences are taught as service courses from one department to another. A second step could be to reconsider the set of engineering sciences altogether, to better support the development of different professions, especially those that take up sustainability more seriously without making it part of their identity. And finally, a third and more ambitious objective could be to rescue the fundamental mission of engineers, designers and architects, which is to conceive, develop, implement, and operate systems of production, consumption and infrastructure in the service of humanity, while recognizing that the highest priority for humanity today is sustainability, and therefore, redesign entirely the way we teach and learn engineering, design, and architecture. In this level of ambition, educational programs would focus on training sustainable engineers, designers, and architects.

The authors of this research note are three teachers and researchers at Aalborg University, who currently coordinate, supervise, and teach at the program of Sustainable Design Engineering. The program is geared towards ambition level three as outlined above. However, to be an authorized engineering program in Denmark, and because of academic administration restrictions, we are still struggling to overcome the first level of ambition, and we are just beginning to experiment with the second level of ambition. In this paper, we will present these experiences and their value to create a sustainable design-based learning approach that is in line with the sustainability agenda. We hope to provide inspiration and contribute to the current debate on design, architecture, engineering and sustainability in education and research.

Sustainable Design-Based Learning: Sketch of a new approach

To integrate sustainable design in the training of designers, architects, and engineers, we propose a new pedagogy that could be called Sustainable Design-Based Learning (SDBL).

From a didactical perspective, SDBL is based on the paradigm of "questioning the world for sustainability" rather than the still dominant teaching paradigm of "visiting monuments in a museum". The instructor's role is that of a supervisor of scientific inquiry for learning. The didactic contract is therefore different from traditional teaching in an engineering or mathematics classroom which focuses on disciplined use of mathematical arguments to find the right answer. Instead, we want students to experience the reasoning behind the concepts and definitions, *before* they are *abstracted*, and *motivate* them to study the sustainability aspects of their design projects.

In SDBL, it will be a requirement that an open-ended sustainable design project in a whole semester or in an engineering course, drives the students' learning of the fundamental topics. It requires that the students use theoretical and practical knowledge to develop a product, a service or a system to tackle a real-life sustainability problem. This pedagogical approach combines problem-based learning (PBL) with project-based learning (PrBL).

PBL is defined as learning that is driven by solving problems, where the self-guided learning process of students is in focus. The learning process starts when students are presented with an authentic problem, and they work in groups to try to develop a viable solution to the problem (De Graaf & Kolmos, 2003). PrBL is closely related to PBL. When students work on a project, PrBL is about the final output of the project, while PBL is about the learning process that leads to the final output. At Aalborg University, project-based engineering, design, and architecture programs started when the university was founded in 1974. Problem-based project work is a fundamental element of all these programs (Kolmos and Fink, 2004).

We propose that the main difference between our SDBL-approach and PBL is in the nature of the problems posed to students: In SDBL, the problems are intentionally designed to be open-ended, authentic, hands-on, and multidisciplinary design projects with the specific objective of advancing the sustainability agenda. In contrast, in traditional PBL, both open-ended and closed-ended authentic problems are normally used to teach a specific topic, which makes it topic driven rather than challenge driven.

We have not been able to identify any program in the world that satisfies the features sketched above. There are studies that show that conventional technical topics are learned better by students when the systematic presentation of principles and theories is complemented by one or several design challenges that motivate students to use technical knowledge to design. That is what Huang et al., (2019) defined as a subject+project approach. Another study reports on "design-based learning for a sustainable future" (Fried et al., 2020). This case reports on a valuable effort to replace the teaching of biological concepts based on sound scientific principles with biological principles to solve sustainability challenges. This initiative builds on biomimicry which is considered one of the current major approaches of design for sustainability (Ceschin and Gaziulusoy, 2016, p. 126).

Some challenges that could face SDBL-instructors include creating design projects with a suitable level of openness, setting learning objectives related to the design process and assessing these learning objectives. Finally, we expect SDBL to be different from the normal project-based learning with respect to the role of the instructor. In SDBL, the instructor supervises students not only at the process and development level, as is usually the case in project-based learning, but also at the technical content level. This is yet another challenge requiring SDBL instructors to be competent in different technical aspects of the design problem at hand and, especially, being open to revising their understanding of technical knowledge and improving it.

Incorporating Sustainability in Engineering Sciences

In this section, we present our experiments with level of ambition 1. Rethinking the role of design in the learning of engineering sciences, without fundamentally challenging its current established delimitations.

Mathematics Through Design

We have been gradually adjusting the contents of an advanced course in mathematics, moving away from the traditional established topics to cover (on the right with deprioritized themes in red) to a more consistent set of topics in line with sustainability priorities (on the left with prioritized themes in green). Many of the topics are the same, but others are not. For instance, graphing 2D and 3D objects, sequences and series strengthens the capacity of students to observe and model natural structures like flowers, branches, spirals, and others that embody biologically occurring geometries that maximize strength, energy intake or protection while using existing resources efficiently. All this knowledge is normally forgotten when only modelling on cartesian coordinates is emphasized in conventional mathematics courses for engineers. Also, more time is given to understand how reality can be modelled mathematically, and how to evaluate its success. In other words, rather than focusing on making the students competent in calculus, the emphasis is on understanding how calculus can be applied to design tasks.

Mathematics	
Sustainable Design	**Traditional**
• Various types of coordinate systems • Applications of calculus • Graphing 2D and 3D objects • Differential equations • Elements of Linear Algebra • Sequences and Series • Sustainable design projects (Can involve other topics in mathematics)	• Polynomials • Complex numbers • Differential equations with complex coefficients • Functions of two variables • Linear Algebra

Table 1.

To illustrate the use of design projects in engineering mathematics, we mention below a design project, given for 1st semester students enrolled in the Sustainable Design Engineering study program at Aalborg University. The students are required to design a birdbath (Fig. 1), using volumes of revolution and integration. The project also involves finding the volume of material used in making this birdbath, and the volume of water it holds when full.

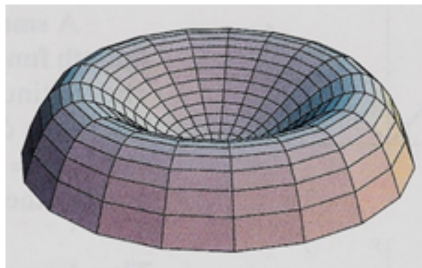

Fig 1. Birdbath

In a traditional engineering mathematics course, students are usually given two curves and asked to find a shape obtained by revolving the region that lies between the two curves around the *y*-axis. These curves are either pure abstract curves or are traditionally related to some industrial or military component which is key for a company, organization, or country to achieve either military or economic advantage over others. Thus, the design is determined, from the beginning, unilaterally by the teacher and embodies unsustainable values, and the problem is merely reduced to calculation, with one single correct answer for all the students. The students are therefore, reduced to a computer and deprived of creativity and engagement.

In our case, we invite the students themselves to define the two curves according to sustainability considerations which can include: optimizing the use of materials, understanding the use of the object in the real physical world, taking measurements, creating an object to fit that reality, and others they might bring into consideration. It is also worth noting that this exercise embodies a fundamental principle of sustainability which is the desire to care for other human beings, animals and nature. This "desire to care for people or animals" Blickenstaff (2005; 375) has been pointed out as a reason why girls tend to prefer life sciences over other STEM possibilities. In our case, this choice incorporates a focus on sustainability as an inclusive STEM strategy, while it underscores a fundamental sustainability principle.

Depending on their design, the students use polynomial fitting and interpolation in mathematics software, such as GeoGebra. This work is conducted in groups, with each group obtaining different answers, depending on their considerations. They present their designs and are inspired by their respective works. A further materialization aspect will be introduced in the next version of the course having the different designs 3d printed, then used as molds in a plastic forming machine to produce the designs to install them on campus for the rest of the semester, for students to observe their designs in action.

Engineering Mechanics Through Design

Typical courses on mechanics that focus on static structures expect students to understand the basics of several topics (right column in the table below). These topics are often presented separately, and students are expected to solve dozens of small exercises to demonstrate their understanding of the topic. Again, the emphasis is on proficiency in the mathematical details of the model, not the understanding of the physical phenomena and how to tackle it when taking decisions for the design of physical objects. In our course, we have replaced the topic of torsion with the mechanical properties of materials. This has been motivated by the fact that students have the opportunity, in their second semester project, to select the materials of a designed object as illustrated below. All the other themes are preserved but not as unrelated topics, and they are constantly addressed to support design decisions, all of which are tightly related to the selection of materials. Additionally, students are introduced to a wider discussion on materials, in contrast to many courses on materials that focus on existing unsustainable materials (aluminum, steel, plastic, concrete) and the normal components that are designed with them (concrete beams with steel rods, for instance).

Mechanics 1	
Sustainable Design	**Traditional**
• Forces and moments • Equilibrium of particles and rigid bodies • Force analysis of structures and systems • Stress and strain • Mechanical properties of materials • Axial deformations • Bending of beams • Shear force and moment diagrams • Deflection of beams • Sustainable design projects	• Forces and moments • Equilibrium of particles and rigid bodies • Force analysis of structures and systems • Stress and strain • Axial deformations • Torsion • Bending of beams • Shear force and moment diagrams • Deflection of beams

Table 2.

In our teaching of engineering science courses, we introduce students to design and energy in the context of sustainability. Here we present two design examples from our teaching of two subjects: strength of materials and dynamics, where we use design projects to drive the students' learning and integrate sustainability considerations.

Fig 2. Pencils

Fig. 2 shows two kinds of pencils: the carpenter's (classical) pencil and the mechanical pencil. The latter uses replaceable graphite cartridges. The tips of these pencils are cantilever beams of varying lengths.

In an introductory engineering mechanics course, students are invited to design a robust pencil tip (hard to break). Students also assess the classical carpenter's pencil. Through this design problem, the students apply the engineering design process to determine the bending stress and choose appropriate materials and lengths of the tips. Moreover, they are required to explain why the chosen design is more sustainable, considering life cycle resource use, environmental footprint, and fulfilling of the function of the product.

Energy conversion and thermodynamics

Perhaps the most astonishing contrast in engineering sciences is the course on thermodynamics. In conventional versions of the course, there is a coverage of the fundamental laws and its applications, and ample presentation and exercises related to the most common industrial uses of combustion engineers, refrigeration cycles and steam cycles in power plants. All of them were established across the globe and were unsustainable processes. They were central to the first and second industrial revolution, but were poor from a sustainable perspective.

Instead, we spotlight the presentation and discussion of efficiency from a sustainability point of view; in terms of resource use, we consider different types of energy and the energetic costs of conversion. In this context, the fundamental laws of thermodynamics inform core considerations for sustainability and cease to be regarded as taken for granted industrial (and military) resources. The subject of efficiencies of engines, heat pumps and refrigerators takes on a new meaning in this course, and is featured last.

Energy Conversion and Thermodynamics	
Sustainable Design	**Traditional**
• Efficiencies of windmills and hydroelectric plants • Types of energy • Properties of substances • Laws of thermodynamics and their applications • 1st law of thermodynamics applied to both closed and open systems • 2nd law of thermodynamics and entropy • Efficiencies of engines, heat pumps and refrigerators	• Properties of substances • Laws of thermodynamics and their applications • 1st law of thermodynamics applied to both closed and open systems • 2nd law of thermodynamics and entropy • Carnot cycle • Refrigeration cycles • Steam cycles for power plants

Table 3.

Exemplary machines

The wind turbine generator shown in Fig. 3 is used in several engineering science courses in the Sustainable Design study program at Aalborg University, to integrate the courses through engineering design. In the Dynamics and Vibrations course, students are required to obtain a value of the average wind velocity for an actual wind turbine in the Copenhagen area. They calculate the input kinetic energy of the wind turbine and search through engineering literature to get the value of the aerodynamic torque T_{aero}. They also determine the angular velocity of the generator rotor, using the gear train ratio. In this way, students are exposed to technologies that have a higher sustainability potential. This appears in contrast to traditional textbooks in dynamics and vibrations in which the design of different parts of cars is emphasized.

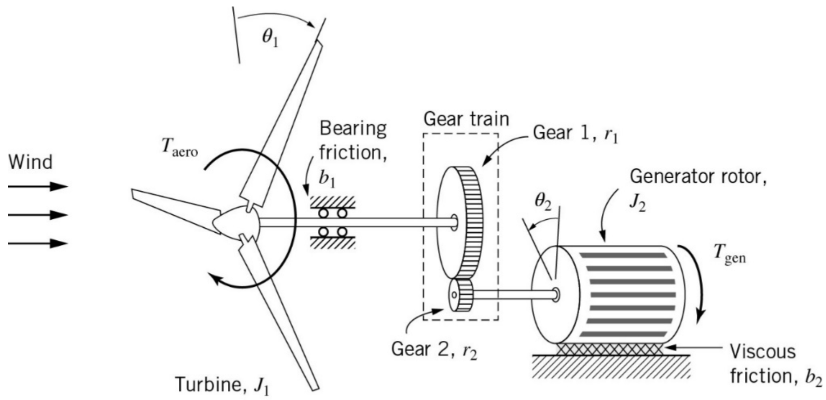

Fig 3. A wind turbine

In the Energy Conversion and Thermodynamics course, students first obtain a realistic value of the electrical power output of the wind turbine and calculate its overall efficiency. This course is key to the training of engineers, and addresses sustainability integrally as a core value. Traditional courses of thermodynamics place too much emphasis on heat energy cycles for the design of combustion engines and refrigeration equipment (Riley, 2011). However, thermodynamics is one of the engineering sciences that is more clearly connected to sustainability and allows for the discussion of relevant challenges looking forward, such as limits of resources, quality of energy and energy efficiency. These relevant topics are normally downplayed or even excluded in courses tailored to produce engineering for the car industry (Wisnioski, 2005).

Finally, in the System Modeling and Simulation course, students are required to draw a block diagram using Simulink and obtain the dynamic response of the wind turbine. They also investigate how to increase the efficiency of the wind turbine and the major factors affecting its efficiency. By including different aspects of the design, use and operation of wind turbines in several courses, students obtain significant exposure to a sustainable technology, and are challenged to learn and develop the areas of the technical courses that are most in line with the sustainability agenda. This also provides a common design object that feeds from several different technical sciences.

Sustainable Design Based Learning: Ambition levels two and three

Ceschin (2014) proposes that designers can no longer restrict their role to that of attending to the requirements of a given client. To be able to fulfil a change of agent role, designers should assume a multi-term design attitude as illustrated in the figure below (Fig. 4). It becomes part of the designer's role to co-define the long-term objective of a given intervention and update it regularly in collaboration with other stakeholders to assess that it is in line with sustainability objectives. The medium-term perspective covers two phases. The first phase requires the staging of socio-technical experiments to test, learn and show what a potential alternative sociotechnical system could be like before it becomes a socio-technical niche, understood as a systemic alternative to established systems (Köhler et. al., 2019). And the second consists of supporting the developed socio-technical niche in the subsequent dynamics of scaling up and becoming a competing alternative to existing established non-sustainable socio-technical systems.

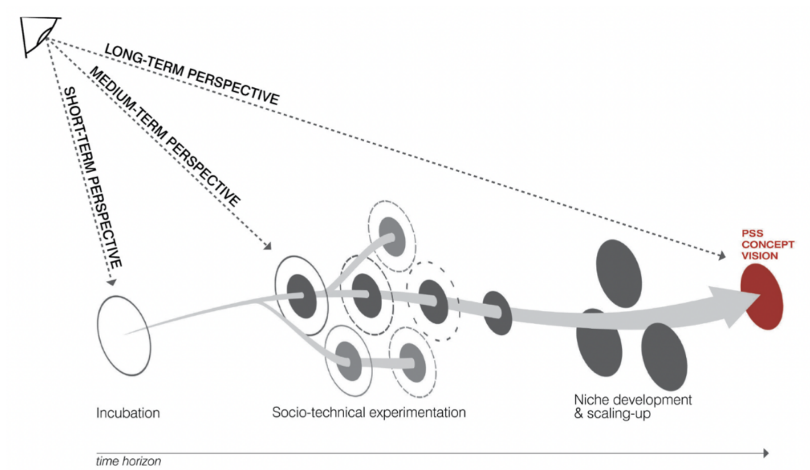

Fig 4. The multi-term design attitude (Ceschin, 2014; p. 14)

And finally, considering long-term vision and medium-term vision, designers must be able to incubate the short-term concepts, ideas, systems that can be matured to become sustainable alternative systems in the future.

To be able to train engineers to do this, educational programs can not restrict themselves to current knowledge and reactive problem-solving focused on useful aspects of the engineering sciences. To be able to train designers as agents of change with vision and the capacity to engage in systemic transformations, programs should focus on:

- Making sustainability the core value of the program
- Framing all semesters as projects to tackle change for sustainability in different forms and at different scales.
- Redefine the role of the engineering sciences to support the two objectives above by placing more focus on the fundamentals of the engineering sciences that are relevant for sustainability, and by selecting input from them that best serves the overall objective.

The Status of Sustainable Design Engineering

In relation to the principles of SDBL, we will briefly present the efforts being made in the Sustainable Design engineering program, to achieve the levels of ambition 2 and 3.

The program, in its current state, is based on a progression in the scale of problem complexity, which is reflected in the theme of the semester. This complexity increases for each consecutive semester, starting with actor-oriented product design in which students are introduced to the basics of engineering design and user involvement. The second semester focuses of re-designing products for sustainability with a technical emphasis. And the third semester centers on the role of prototypes in design. The first three semesters are product centered. In the fourth semester, the project shifts to product service systems, and there is greater emphasis on life cycle analyses, dematerialization, and the circular economy. In the fifth semester, students tackle challenges at the level of sociotechnical system design. And in the final semester, they are free to choose the emphasis. This progression from products to services to systems is coupled with a progression in the discussion of sustainability. As established by Ceschin and Gaziulusoy (2016, 2019), the sustainability potential of designing products is very low compared to that of services, and designing sociotechnical systems is the approach that has more potential. The challenge here is that the bulk of design knowledge, whether in commercial products or buildings or established engineering objects, such as bridges, mechanical machines, and electronics, is on material products. Given the extensive knowledge related to material products in these discussions, sustainability becomes an afterthought or an additional criterion, and not the core value.

There is growing literature on designing services where dematerialization, cradle to cradle and the circular economy are given greater attention, and therefore, there is increased discussion on sustainability. There is an incipient discussion on designing sustainable socio-technical systems, where sustainability can, in fact, be the leading value integrally from the beginning (Pineda and Jørgensen, 2018). In short, there is an ambition that belongs to level 3 in the way the program's semester progression is conceived.

However, as we can see in Figure 5, the engineering sciences (highlighted in green) are still disconnected from the semester project. This happens for two reasons. The first is that to be accredited as an engineering program, the engineering sciences must be part of the program. And the second is that many of them are delivered as service courses by other departments in the university. In some of the courses, we have been able to implement changes as outlined in the first part of this research note. And we have changed the focus of one of the courses. In fact, Fluid Mechanics was replaced with System Modelling and Simulation in the fifth semester. This last course still covers many aspects of the first one, but the focus is on systems, rather than on flows, which matches better the theme of the semester.

	5 ECTS	5 ECTS	5 ECTS	5 ECTS	5 ECTS	5 ECTS
1	Actor-oriented Design	Design processes and visualization		Fieldstudies and socio-materia l analysis	Modells, mechanics and materials	
2	Re-design for sustainability			Products, use and context	Vibrations and regulation	Thermo-dyna mics
3	Design and use of prototypes			Co-design and user involvement	Logic and programming	Signal analysis
4	Design of product service systems		System visualization	Networks and change	Science Theory	LCA
5	Design of sustainable systems			Sustainability and Society	Fluid Mechanics	Applied Statistics
6	Final Project			Creative project leadership	Strategic concept development	Information gathering on physical and material phenomena

Fig 5. The Sustainable Design study program at Aalborg University

Although we have local support to cover the three levels of ambition, if we must be honest, we are only seriously experimenting with level 1 both in the courses that we teach ourselves, such as Dynamics, Thermodynamics and System Modelling and Simulation. But in the other technical service courses, our room for maneuver is more restricted. The program has a structure that belongs to level of ambition 3, but we have only incipient ideas on how to grapple with level of ambition 2.

Discussion

With the field of engineering commonly viewed as being close to science, the engineering sciences acquire a key role in any discussion on science and design in relation to an engineering education. Programs that build on the engineering sciences but have an applied and explicit professional practice, such as engineering design, architecture engineering, and Sustainable Design Engineering (SDE), do not fully conform to the association with the sciences. Their identity is strongly influenced by the design purpose of the profession, which is more associated with acting on the world, even if all the scientific evidence to support such actions is not complete. This creates a dichotomy between science as true demonstrated knowledge, and design as informed action.

One of the points of contingency in the discussion between Farell & Hooker and Galle & Kroes is whether such a distinction can be made between science and design, by studying their respective core focus. The argument is that “the natural sciences are concerned with how things are […] Design on the other hand, is concerned with how things ought to be, with devising artifacts to attain goals” (Galle & Kroes, 2014, p. 202). This argument is reflected in many design and architecture programs in that students are encouraged to go out and learn from what exists, by observing and conducting experiments, and then apply this knowledge in novel ways to deal with complex real-world problems to change and improve them. This practice supports the notion of ‘co-occurrence’ of science and design as presented by Galle & Kroes (2014).

The discussion on ‘co-occurrence’ is motivated by Farell & Hooker (2012) about science and design dealing with technical artifacts, on two different scales: the inner and outer environment of a designed object (a product, building, bridge). On this topic, Farell & Hooker (2012) state that science is primarily concerned with the inner environment. In their words, science deals with “[…] the substance and organization of the artifact itself” (p. 482) and design is primarily interested in the outer environment: “[…] the surroundings in which it operates” (p. 482). Galle & Kroes (2014) call for a more integrated approach stating that “[…] designers are able to bridge the gap between a functional description of an artifact and the structural description that is a prerequisite for producing such an artifact” (p. 204), which means that designers are required to deal with both the inner and outer environment, to ensure that their design can fulfill its intended purpose.

Our argument in this paper supports the position held by Galle & Kroes (2014). We add to this argument that science and design cannot be separated when the purpose of design and the direction of society’s development also becomes part of the responsibilities of designers, architects, and engineers. Maybe this is what was taken for granted when the engineering sciences were developed and engineers, as well as designers and architects, were perceived as experts delivering science-based solutions to problems which were posed by other experts such as client firms, politicians, economists, and public administrators. Maybe in that world Farrell & Hooker’s distinction did exist.

But as we progress into the second decade of the 21st century and the climate emergency becomes more urgent than ever, designers, engineers and architects must be trained as change agents for sustainability. The sustainability agenda is about creating a world that is radically different from the current one (Sachs et al., 2019; Randers et. al., 2019) which requires both sound criticism of what exists, and an innovative attitude at all levels to what should exist. Which in turn requires that professionals consider the inner workings and the context of what is designed. And this in turn requires solid and improved training in the natural and the social sciences in a way in which sustainability is a core value of both. This is what we are aiming for with the program of Sustainable Design Engineering at Aalborg University, where we still struggle with the legacy of a modern type of training that considers science and design as separate and sequential parts of the training of technical experts.

Conclusion

In this paper we have approached the question of how to re-think the engineering sciences for sustainability. We have exemplified a proposal for design-based learning of the engineering sciences based on our engagement in the education of Sustainable Design Engineers in a Problem Based Learning environment. However, we have kept the detailed discussion and the examples at the level of individual technical courses. With this we recognize an institutional global reality, which is that what defines a program as an engineering program is that it covers the basic engineering sciences. But this also makes this discussion relevant for any other program in design engineering, mechanical engineering, production engineering, architecture design and others, in which teachers are interested in bringing design and sustainability into the training of engineers as an integral competence. As Bucciarelli and Eder (year) have lamented, design has unfortunately been removed from the training of engineers in favor of what is considered a more systematic and structured development of technical knowledge. However, this has resulted in a situation where engineering, design and architecture students in general, have too little exposure and training in design competencies and often, they become detached of scientific and technical knowledge. Additionally, what humanity needs most in this historical moment is increased technical and organizational capacity to deal with the challenges of climate change, resource depletion and social inequality, or in short, sustainability (Sachs et al., 2019; Randers et al., 2019). We have argued that it is our duty as engineering and design educators to bring back design and introduce sustainability as a fundamental competency to be developed integrally through the curriculum.

We propose three levels of engagement. The first one consists of better selection of the content of engineering sciences and replacing the examples used in technical courses. Traditionally, these have become either very abstract examples, detached from reality, that only challenge the students to focus on the scientific relations expressed in mathematical equations to be remembered, and their capacity to use them consistently. Or they have been focused on technologies and processes that are inherently unsustainable, such as different aspects of combustion engine car designs, missile and bullet trajectories, conventional power plants, steel and concrete as the main materials to be studied and understood, and so on. We have presented three examples that focus on designed objects and technologies that could become sustainable or are core technologies in current sustainable systems (windmills).

More can be done. Instead of treating sustainability as a secondary social value to be addressed after conventional training in the basics of engineering, at Aalborg University, we have developed a whole design engineering program which has sustainability as its fundamental focus. We consider this to be our second level of engagement. Our focus on sustainability is integral to the entire education curriculum and has been implemented during the last ten years, especially in the project component of the education system. Our reflections on how to adjust the engineering sciences to this profile has emerged as a clear need because students experience the dislocation between technical courses and design courses and projects. More programs in the world could attempt similar integration, but the reality is that currently the average engineering and design programs have a structural non-negotiable focus in conventional engineering sciences, while design is addressed only in the last semesters or, in many cases, only in the last semester as a capstone project. Even worse, sustainability is often treated as an elective lecture or course in engineering.

A third level of engagement becomes, for us, an open invitation to the wide community of engineers and designers globally. Just like we cannot expect to learn conventional engineering sciences and then apply them to sustainability challenges, we cannot aspire to simply apply existing knowledge, tools, and methods to current and new global challenges. Achieving sustainability requires "radical changes [in the way] societal functions are fulfilled…at the 'meso' level of socio-technical systems" (Köhler et al., 2019). Therefore, we should be engaging in a more ambitious agenda to create a design and engineering profession and practice that can support the design of systems that reach absolute sustainability (Hauschild, Kara and Røpke, 2020). Blizzard and Klotz (2012) have addressed the need for whole system design for sustainability. Ceschin and Gaziulusoy (2016, 2019) have created a comprehensive review of emerging design approaches for sustainability. However, we are missing discussions on how to adopt these in the education of engineers and designers as an integral fundamental aspect of their professional identity.

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