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Learning about energy. A real-life approach challenging the present culture of science & engineering

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Abstract.
There is an increasing number of publications in various fields of research suggesting that a purely technocratic approach cannot mitigate the current environmental crisis caused by climate change. This goes hand in hand with the criticism expressed by science educators that classroom teaching on energy is mainly based on the conceptual knowledge perspective of science education, which is considered inappropriate for empowering young people to fight in the best interests of the biosphere. Based on the experiences gathered in the R&E project "SOLARbrunn – heading for a future with the sun" the paper highlights some facets of STEM education which seem to be indispensable for empowering young people to contribute to sustainable development. In an interdisciplinary research setting modelled upon Zeidler's conceptual framework for socio-scientific issues, students at a Secondary Technical and Vocational School in a small Austrian town worked out suggestions for converting a local kindergarten into a 'green building'. In the course of the project, the traditional view of engineering - constructing technological solutions based on the rigorous mathematical processing of data acquired by diligent measurement – was challenged. When dealing with real world cases where everyday routines are important for planning, implementing and adjusting technical systems, the limitations of the technocratic approach to sustainable development becomes evident. Sustainable development is less a question of enhanced technology; it is rather a question of improving socio-technical practices by means of interactive efforts on the part of various players.

Key words. sustainable development, situated learning, socio-scientific issues, culture of STEM, socio-technical systems, green building

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Introduction

Energy is not only one of the most important concepts in science; it is also an issue of great economic and political significance in modern society. The supply of renewable energy and the efficient use of energy are seen as key steps towards finding solutions to the current environmental crises brought about by climate change. However, classroom teaching on energy is still mainly defined from a conceptual knowledge perspective of science education and does not pay attention to the complex and multi-faceted environmental and societal challenges that face us today. This is particularly due to the so-called "economic imperative" that dominates science education today (cf. Donovan, Mateos, Osborne, & Bisaccio, 2014). The justification of STEM education by the "economic imperative" is based on a number of macroeconomic studies which link the achievement of students in maths and science (e.g. PISA) with the growth of gross domestic product (GDP) (e.g. Hanushek & Woessmann, 2012). From this perspective, the primary goal of STEM education is to produce students who will pursue STEM careers and therefore help maintain continuous economic growth, enabling economies to compete effectively on the global market.

However, these ideas are misleading for various reasons:

(1) They ignore the fact that, in the long term, the impact of economic growth puts limits on biodiversity and has a negative effect on ecosystems, and therefore also limits the potential for future economic growth.

(2) They rather reinforce the status quo as technological solutions primarily concern the symptoms and not the causes of the problem.

(3) They delegate the solutions for environmental problems to experts, thus disempowering citizens.

(4) They fail to take account of the fact that both the environment and technology are social constructs and are thus inextricably linked up with economic resources and power.

Therefore the "economic imperative" of the STEM pipeline "falls short of empowering students to assess, preserve, and restore ecosystems in order to reduce ecological degradation and increase economic welfare" (Donovan et al., 2014, p.1).

Reducing the emission of greenhouse gases necessitates a substantial redirection of energy systems towards greater sustainability. For this purpose the European Union's Energy Strategy targets an increase in the share of renewable energy supplies to a level of at least 20% by 2020 (and 27% by 2030) and an increase in energy savings of 20% or more by 2020 (and 27% by 2030) compared with the business-as-usual scenario of energy consumption[1]. One important response would be to intensify research and innovation; another would be to translate these objectives into concrete decisions, investments and practices, not only at a national but also at a regional level. Sustainable development therefore compels engineers to reflect on the ecological, economic and social impacts of new technologies on today's and tomorrow's societies when constructing technological devices. However, sustainable development also compels citizens and politicians to actively participate in societal discussions and reach informed decisions, on a personal as well as on a political level, in order to initiate a transformation of our society into a more sustainable one. As sustainable development cannot be accomplished without questioning western lifestyle with its dominant patterns of production and consumption, the discussions about concretizing objectives, formulating priorities and developing strategies are highly controversial.

The literature highlights the fact that education and, in particular, a change in (young) people's awareness is of particular importance for achieving the ambitious goals of sustainable development. Participating in controversial discussions and decision-making processes in this context demands skills and abilities such as "acquisition and assessment of information, the capacity for communication and cooperation,

1 https://ec.europa.eu/energy/en/topics/energy-strategy-and-energy-union/2020-energy-strategy
https://ec.europa.eu/energy/en/topics/energy-strategy-and-energy-union/2030-energy-strategy

and foresighted planning in linked systems" (de Haan, 2006, p. 21). STEM approaches in the context of sustainable development must therefore not only contribute to students' personal intellectual knowledge but also to their ethical development. For this purpose a number of science educators (Hodson, 2003; Sakschewski, Eggert, Schneider & Bögeholz, 2014) have suggested "functionalizing" scientific literacy into an issue-based curriculum. In such a curriculum "social, economic, political, and ethical issues are taken into consideration and are closely linked to STEM learning. In this way, it is hoped we can empower young people and prepare them for socio-political action 'in the best interest of the biosphere'" (Hodson, 2003, p. 645).

This paper takes up these considerations and investigates how a teaching-for-sustainability approach can be integrated into the curriculum of a secondary technical and vocational school. It focuses on the sustainable supply and use of energy in a public building as about one third of the energy required by the European Union is used in the private and service sectors. Energy efficiency and renewable energy supplies as well as their economic viability play a decisive role in the education of future engineers. In addition, investigating energy use in a public building includes considerations of the health and everyday practices of the users. Furthermore, sustainable design is not only a configuration of technical structures in response to a situationally specific analysis of an environmental challenge in a more or less successful way. It is rather "a social expression of competing ecological values" (Guy & Moore, 2005, p. 9), a result of competing discourses, framed by dynamic social, technical and political contexts. Therefore, investigating the energy use in a public building and proposing measures for transforming it into a sustainable building demands an arena for meaningful discussion and critical reflection between the various stakeholders in order to figure out how their different interests affect the conceptualization of sustainable design. Thus, according to Guy and Moore (2005, p. 9), a sustainable building is not a result of best technological practise vis-à-vis accepted environmental standards; it is rather "an assembly of ideologies, calculations, dreams, political compromises and so on".

Theoretical Background

Teaching for Sustainability

Since the concept of Sustainable Development was introduced by the United Nations (1987) in the so-called Brundtland paper, there have been a number of world congresses for elaborating what measures can be taken on an individual as well as on a societal level for developing answers to and strategies for the world's environmental and social problems. Amongst these congresses, the Rio conference in 1992 highlighted the vital importance of education as achieving sustainable development requires a global change in mindsets, beliefs and behaviours. Despite all these efforts and although sustainable development is accepted as a normative framework for politics, the economy and education worldwide, the concept remains elusive and its implementation challenging. In this paper we will rely on the widely accepted three-pillar model, which suggests that sustainable development can be achieved by balancing economic development, social equity and environmental protection. Referring to the three-pillar model, sustainable engineering can be understood as design under ecological, economic and social constraints. Thus, teaching for sustainability must deal with impacts on ecology, economy and society on local, regional and global levels (de Haan, 2006).

Framing learning about energy as a Socio-scientific Issue (SSI)

The above-mentioned ideas suggest that orienting learning about energy towards Education for Sustainable Development[2]

2 The term Education for Sustainable Development is applied by the United Nations organizations, such as UNESCO https://en.unesco.org/themes/education-sustainable-development or UNECE (https://www.unece.org/env/esd.html), for describing the practice of teaching for sustainability. While the translation 'Bildung für Nachhhaltige Entwicklung' is also frequently used

requires an interdisciplinary context that is broader than the usual conceptual and technological approach. For this purpose science education research proposes framing teaching about energy as a socio-scientific issue (SSI). Although the domain of SSI is related to the science-technology-society (STS) movement, SSI remodels the STS approach by adding considerations about the ethical dimensions of science as well as the students' emotional development and their ethical/moral reasoning (Zeidler Sadler, Simmons & Howes, 2005, p. 360). While STS has been defined as a context for science education (Yager, 1996), the SSI approach is a pedagogical strategy which explicitly focusses on the empowerment of students by helping them to reflect "how science based issues and the decisions made are concerning them" (ibid.). Thus, considering how controversial scientific issues and dilemmas affect the intellectual growth of individuals in both personal and societal domains is the key concern of SSI education. SSI issues therefore have their basis in science; possible solutions, however, involve ecological, societal and ethical considerations (cf. Oulton, Dillon & Grace, 2004; Sadler, 2004; Sakschewski, Eggert, Schneider & Bögeholz, 2014). Related problems like energy storage technologies, the construction of off-shore wind power systems, a reduction in private traffic or the specific design of energy-efficient buildings are often ill-structured, their solutions multifaceted (cf. Sadler, 2009, p. 11). Because of the social significance of SSI, scientific data underdetermines strategies of resolution. Besides, these problems are not only complex challenges for science and engineering, they are also ethically and politically complex for individuals and different groups within society who have competing perspectives and priorities that generate both interest and controversy. For instance, the energy performance of energy-efficient buildings is not only determined by the technological components used in construction but also by the interplay of the specific devices installed (e.g. the heating and ventilation systems) and the way occupants become acquainted with and are supported in their use of such devices (cf. Rohracher, 2005, p. 208). Consequently, the real-world performance of clear-cut technological solutions designed by experts in the lab is highly dependent on contextual factors.

Although there is broad agreement within the science education community that the implementation of SSI is fundamental in today's science education classrooms, the implementation of SSI in STEM curriculums and everyday classroom practice faces some difficulties, especially in physics and engineering (Sakschewski et al., 2014, p. 2293). The reasons are manifold: disciplinary purity or rigour (Hodson, 2003, p. 660), the challenges of teaching the complex concept of energy (Driver & Millar, 1985), and the perception of physics and engineering as 'hard' science disciplines which exclude 'softer' socio scientific orientations (Zeidler, et al., 2005, p. 360). Yet, if we acknowledge the necessity of sustainable development, we need both groups: citizens who are able to discuss and critically judge energy-related decisions but also scientists and engineers who are able to include the socio scientific perspective in research and innovation. As SSIs support the development of reasoning skills and the appreciation of the merit of evidence in everyday decision making, opening STEM education to SSI is important in academic and vocational education alike.

In order to implement socio scientific issues in science education practice and research, Zeidler et al. (2005) have proposed a framework which links science education research with sociological, psychological and developmental factors. This framework can be thought of as entry points in a science curriculum which contributes "to a student's personal intellectual development and in turn, helps to influence teaching in science education to promote functional scientific literacy" (ibid. p. 361).

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by German-speaking educators, the equivalent term 'teaching for sustainability' will be utilized in the article as it is the current terminology in the English-speaking world.

The conceptual model of Zeidler et al. is based upon the analysis of a huge amount of science education research literature regarding SSI and it identifies four areas of pedagogical importance central to teaching SSI:
(1) nature of science issues
(2) classroom discourse issues
(3) cultural issues
(4) case-based issues.
Controversial socio-scientific issues provide an environment where students become engaged in discourse and reflection. Being exposed to or challenged by the arguments of others in classroom peer discussions provides a rich opportunity to analyse the quality of claims, warrants, evidence and assumptions among competing positions. Moreover, epistemological stances regarding the nature of science (NOS) influence how students evaluate scientific data. Therefore, explicit instruction in NOS and careful evaluation of evidence regarding SSI is of crucial importance as it helps students evaluate any kinds of claims, scientific or otherwise.

As 21st century science classrooms are highly pluralistic and sociologically diverse, students approach controversial issues from a variety of everyday experiences, worldviews and sets of values. Encouraging the expression of these diverse perspectives is an important feature of SSI learning environments as they require identifying and critically examining one's own interests and desires as well as the ability to understand another person's cultural context. The variety of cultural values, desires and interests opens rich opportunities for classroom argumentation and discourse. To make themselves open to various solutions to a problem, students have to have an understanding of their peers' worlds; they have to connect with them intellectually and emotionally. This supports empathy and ambiguity tolerance.

Situated Learning as a theoretical lens

When viewing learning about SSI through the theoretical lens of situated learning, the specific social and cultural environment of the learning process becomes significant. According to Lave and Wenger (1991) these environments, which

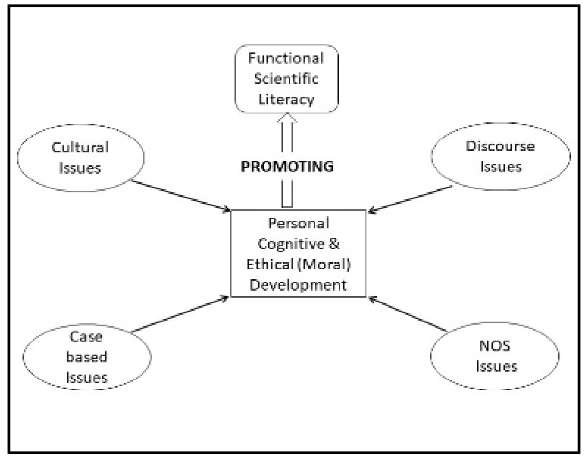

Figure 1: Framework for teaching socio-scientific issues (Zeidler, Sadler, Simmons & Howes, 2003, p.361)

they called "communities of practice", are formed by those who participate in the learning process, the available ideas, tools and resources as well as the cultural norms, both tacit and explicitly stated, which guide interaction and communication. Consequently, learning cannot be considered an isolated process that occurs in the minds of individuals; learning rather requires an understanding of how to function within the specific community of practice.

If learning is not only viewed as a cognitive but also as a social activity, the process of learning goes beyond acquiring facts, concepts and skills; it is "more basically a process of coming to be, of forging identities in activity in the world" (Lave, 1992, p. 3). Hence, when students participate in a community's projects, they appropriate specific facets of its culture. As student develop a growing understanding of the specific culture, they are then able to engage in more elaborate discourses and activities. Learning, as understood by Lave and Wenger, is therefore rather enculturation into a specific culture. As a result of this integration into a new culture, apprentices gradually gain new ways of behaving and acquiring new best practice methods. According to Gee (2000) this goes hand in hand with the integration of new facets of identity. Thus, education understood as enculturation into a specific community of practice "must strive to open new dimensions for negotiation of self" (Wenger, 1998, p. 263).

The culture of STEM classrooms is established by the specific routines carried out, the (implicit) rules followed and the aims shared by teachers and students. Although there are significant differences between the culture of STEM classrooms and the culture of academic STEM disciplines, they are intrinsically linked to each other. They share a focus on specific phenomena; the scientific ideas taught at school, though simplified and abstracted from the context, are the same as those derived and used in research. Usually a wide array of equipment and tools is found in STEM classrooms which are very similar to the ones used in STEM research, albeit used in a different way from their original intent. Moreover, there are certain habits, rules and modes of discourse and enactment that are thought of as distinguishing a STEM person from others that reveal themselves during school science learning. Students who can identify with these rules and habits are recognized as STEM persons by their teachers and their peers.

From the perspective of situated learning, the fact that the transfer of tools and concepts strips "these resources of their cultural significance" (Sadler, 2009, p. 9) leads to a dichotomy as the aims of STEM education (understanding well-established concepts and formalism) and STEM research (creating new understandings of the natural world by using scientific formalism and practices to answer, ask and solve new questions and problems) are completely different.

There are some initiatives to bridge the gap between the two cultures by providing learners with authentic research experiences: e.g. Research and Education collaboration projects where students collect data which is incorporated into scientists' work or extracurricular programmes where students work as research apprentices. Although these programmes are successful to some extent, they are also criticized as they may alienate "many students who lack the interest and motivation to cross 'cultural borders' into professional science" (Sadler, 2009, p. 11 referring to Aikenhead, 1996).

Sadler (ibid.) therefore proposes to establish "science as it is practiced in the living experiences of engaged citizens", which can offer an alternative to the dissatisfying dichotomy between the two cultures – the one of the science classroom and the one of the science community. The basis for developing this different kind of community of practice in STEM classrooms is the implementation of socio-scientific issues in STEM learning environments. Establishing such communities of practice plays an important role in teaching for sustainability. Because of the social significance of these problems, their exploration requires not only a negotiation of scientific concepts, principles and practices, but also of interests and values. These aspects are a prerequisite for raising students' awareness, which is an important feature of education for sustainable development.

The importance of the gender lens

There are several reasons why the gender aspect was important in the project: The field of science and engineering is gender-biased. There is an imbalance in the participation of men and women worldwide and, what is even more important, scientific knowledge, like other forms of knowledge, is culturally embedded and therefore reflects the gender (and racial) ideologies of societies. Although environmental issues were originally considered a 'soft' science and political issue, "the growing attention to climate change has been accompanied by a relocation of the centre of environmental debate and action to […] the scientific and policymaking institutions" (MacGregor, 2010, p. 230). Hand in hand with the change in the perception of environmental problems, sustainable development has been redefined as an exclusively techno-scientific problem which requires technical solutions. As a consequence, ecological problems related to climate change have become "hardened" and have brought "men to the fore as policy experts, scientists, political advocates, entrepreneurs, commentators and celebrities" (ibid.). What is more, these discourses have led to a 'masculinization' of environmental politics. Besides, these approaches are responding to the symptoms rather than working towards a sustainable global development, as already mentioned. Therefore it is important to focus on the cultural and symbolic dimensions of processes through the gender lens, thus unveiling the hidden (masculine) norms and power relations which shape the discourses of sustainable development.

This paper investigates how dealing with a socio-scientific issue in the context of sustainable development interacts with the culture of a secondary technical and vocational school. In particular, we wanted to find out how a real-life approach can contribute to a more inclusive perspective on energy teaching and, at the same time, raise awareness of the limitations of a purely technocratic approach to ameliorating the environmental crisis.

The project SOLARbrunn – heading for a future with the sun

The collaborative Research & Education project, "SOLARbrunn − heading for a future with the sun", was modelled on the conceptual framework for socio-scientific issues elaborated by Zeidler et al. (2005). The specific case we want to look at involved a kindergarten building in Hollabrunn, a small town in Lower Austria. This was a real-life situation which students at the local Secondary Technical and Vocational School (HTL – Höhere Technische Lehranstalt) investigated in their diploma theses, part of their school leaving examinations. They were supervised by their teachers, student teachers majoring in physics and an interdisciplinary team of scientists (a physicist, a science educator and a social anthropologist). They had to find research-based suggestions to convert the kindergarten into a 'green building'[3] which should reflect the needs and expectations of the kindergarten's staff and children. As the main objective of SOLARbrunn was to reconstruct scientific/engineering knowledge against the background of sustainable development for solving local problems, the students and their teachers conducted the research process themselves while the scientists assisted and facilitated the process. This stands in contrast to the usual practice of research and education projects, where students collect data which are incorporated into the scientists' research. Instead of producing knowledge to be objectively validated by scientific discourse, the SOLARbrunn project intended to produce what Bammé (2005) calls "socially robust knowledge", i.e. knowledge which is integrated into the local living environment of the municipality of Hollabrunn. SOLARbrunn therefore does not only have to consider scientific aspects but also economic and social ones as well as aspects of power. To cover all these facets in a creative way, the project made use of a complex stakeholder process where the above-mentioned research team (HTL students and their teachers, scientists and student teachers majoring in physics) formed a community of practice together with members of the town's municipal government and the staff of the kindergarten. The advantage of this strenuous, time-consuming, contradictory and sometimes highly emotional process was the production of knowledge that the community can rely on in further energy management and construction projects. In addition, this could be an impetus for the organizational development of the HTL establishing itself as a key player for promoting sustainable development in the region.

Thirteen students in all from the different departments at the HTL took part in the research process. The students volunteered to participate in the project by choosing to write their thesis there. The specific objectives were created collaboratively by the research team and the HTL teachers and were aligned with the various vocational focuses. The final formulation of the research questions for the diploma theses was the result of a stakeholder process which the HTL students participated in. The electronics students worked on climate monitoring and designed a 'CO_2-signal light' for collecting comfort data (CO_2, humidity, temperature) remotely. The students in mechanical engineering developed ideas for adapting the

3 Green Building is a systematic approach to designing and constructing houses which embraces the complex and diverse needs of the occupants and users and at the same time fosters sustainable use of energy and natural resources (Johnston & Gibson, 2008).

regulation of the ventilation and enhanced shading systems based on an analysis of the comfort data collected. Based on an energy consumption analysis, the students from the department of electrical engineering developed suggestions for sustainable energy management and investigated the potential for installing a photovoltaic plant. The students from the industrial engineering department were responsible for project management, communication and investment calculation but they also collected the necessary social data regarding the particular needs of the kindergarten's staff and presented them in a 3D-visualization of the kindergarten building. Thus, they took the lead in the project.

A key aspect of the project was that the 'learning environment' was an 'ill-structured' real-life-case, i.e. the energy management of a recently built public kindergarten in a small Austrian town. This, however, implies that learning about sustainable use of energy transgresses the intimacy of the classroom. Problems 'out there' are not clear-cut assignments and although theoretical knowledge and engineering skills are good guides, decisions in the research and development process have to consider social, political and economic interests as well as the values of the stakeholders involved. In short, sustainable technological solutions have to be created under ecological and social as well as economic and legal/political constraints.

Research Design

The specific goal was to find out to what extent the collaboration with researchers and the focus on teaching for sustainability affected the process of the students writing their diploma theses. Moreover, we were interested in learning how the specific setting affected traditional perspectives on teaching STEM.

At the beginning of the research process, a 4-R analysis[4] was conducted to clarify the roles played by the different stakeholders and the relationship between them. To provide a "thick" description of the ongoing processes in accordance with Geertz (1973, p. 10), a vast amount of data was collected. There were 24 departmental meetings altogether which were audio-recorded and fully transcribed. Additionally, the students, their teachers, student teachers and members of the scientific team as well as the school's headmaster, the heads of the four departments and the local environmental councillor (who was also a teacher at the school) met at three interdepartmental meetings. These meetings were documented by minutes. Moreover video-records were taken which were partly transcribed. At the interdepartmental level there were four more meetings attended by the teachers, the local environmental councillor and the scientific team which were documented by minutes. Most of them also were audio protocolled and partly transcribed. Furthermore, the scientific team, one teacher from the HTL's project team and the HTL's headmaster met the head of the kindergarten and 2-3 members of the town council at four stakeholder meetings. These meetings were documented by minutes. Another important database is the five diploma theses the students wrote as part of their school-leaving examinations[5].

At the end of the project the four main teachers were interviewed, as were 11 of the 13 students[6]. We were interested in the motivation behind participating in the project and the role that sustainable development and research played in the diploma thesis process. The interviews were audiotaped and fully transcribed.

The methods for subsequent analysis were chosen depending on the character of the document. A deductive path content analysis (Mayring, 2003) and a key incident analysis (Kroon & Sturm, 2000) were used for highly structured documents like the minutes or the diploma thesis. For the rather low-structured

4 http://www.policy-powertools.org/Tools/Understanding/docs/four_Rs_tool_english.pdf

5 At the HTL the diploma theses are written in teams of two or three students.

6 Two of the students graduated one year earlier. As they only participated in part of the process, we did not interview them.

documents like the transcriptions of audio protocols or the interviews we followed a rather inductive path involving an applied discourse analysis based on the documentary method elaborated on by Ralf Bohnsack (1998). Thus we tried to reconstruct elements of the engineering culture which guided teaching and learning.

Results

The 4-R analyses revealed the crucial role of the head of the kindergarten: although not directly involved in the research process, she was the gatekeeper for data collection. Furthermore, the town that was responsible for running the maintenance of the kindergarten had to be considered as an important project partner as they had the necessary resources as well as the legal power to implement the proposed refurbishing measures.

The first draft of the investigation plan, as elaborated by the students together with their teachers, just involved the collection of technical data. However, the minutes provide evidence that it soon became clear that collecting technical data would not suffice to transform the kindergarten into a green building:

> Mr. E. (teacher industrial engineering department): *"I was informed by a colleague … about platforms which help to connect specific investments and their benefits – a lot of Excel sheets. … I am pursuing that track – automatizing as much as possible. But in the end everything is different … . We don't need these investments and how they affect energy consumption or things like that, we have to follow the social track!"* [Audio protocol departmental meeting 100615, Ll05-115[7]].

In order to interpret the measurements, social data about the everyday routines at the kindergarten also had to be collected. The students from the industrial engineering department designed a questionnaire for this purpose aided by their teacher, the student teachers and the social anthropologist. In accordance with the request of the kindergarten director, Mr. E., the HTL students' teacher, conducted the interviews with the kindergarten staff. The analysis of the interviews was of key importance for the whole research process as it helped to focus the research questions and steer the whole process. In the course of the project, it became clear that all of the students had to collect social data in addition to the technical ones. They could count on the help of their colleagues from the industrial engineering department, but they had to draw up drafts of the questionnaires and do interviews themselves. Yet, the idea of collecting 'soft' social data did not appeal to all of the participating teachers and students: As mentioned earlier, the electronic engineering students developed an indoor environmental comfort data recording device with signal lights, which could be used for aligning the settings of the ventilation system with the comfort data, especially the concentration of CO_2. In one of the meetings they expressed their disappointment that they had not got any feedback. However, as the students had just installed the device without explaining how it worked, it was not surprising that the kindergarten staff did not understand its functionality. Although it was clear that non-experts could not interpret the signals of a device whose operation mode they did not understand, the teacher did not ask the students to explain the device to the staff.

> Mr. C. (teacher electronics department): *"Do you want to make me a sociologist? … Electronic engineers do not bother about the user, they only build devices! … This is the reason why we decided that the industrial engineers deal with the sociological components".*
>
> Mr. M. (teacher mechanical engineering department): *"Well I am a mechanical engineer and these steps were also quite new for me, but to tell you the truth, we gained useful information for the analysis."*
>
> Mr. C.: *"I only took two 'skilled engineers'[8] to do this job – they are not interested in working with people. I can't make them be that, I would lose face in front of the boys. This was not part of the agreement for the*

7 All quotes were translated by the author.

8 orig.: Vollbluttechniker – literally translated: "thoroughbred engineers".

> *diploma thesis"* [Audio protocol 261115, L65-238 excerpt].

In the end, the 'skilled engineers' gave a short demonstration to the staff of the kindergarten on how to use the device.

In their diploma theses all of the students followed the standards of scientific publications and developed data-based suggestions for optimizing the indoor environmental comfort of the kindergarten building which had been built to low energy standards. At the time the building was constructed, the legal regulations aimed primarily at lowering energy consumption but did not reflect the users' comfort. Therefore, the results of the investigation clearly confirmed that the temperature was too high (primarily on the top floor) due to solar radiation and a lack of adequate shading. Additionally the humidity was rather low (10-20%) during the heating period due to the construction and settings of the ventilation system.

The interviews, however, provided evidence that the students struggled with the long-term process of defining an approach to the problem.

> "*At the beginning, after our first meeting we had to bring some suggestions for optimization. Well, we thought of very different things than we proposed in the end. … The vision we had in the beginning changed ten times. But I would not say that the idea in the beginning was good and the end bad, definitely not!"* [Int.StudME2, L166-173].

Another problem that was raised frequently in the interviews was the regularity of the meetings and the problems of communication between the departments:

> *"It took some time, I think until the second meeting, until we found out to whom the tasks were assigned and only then were we able to find a way to deal with the tasks. And then we launched the WhatsApp group … but in the beginning … everyone was working more as an individual than as part of a team"* [Int. StudIE1, L45-109].

While some of the students felt that "*the time invested* [in regular discourse] *was not supportive in making progress in the completion of diploma theses"* [Int. StudEl2, L85], for others it was motivating that *"there was always someone who was interested in our progress"* [Int. StudME1, L76]; this helped them to move forward and to improve.

However, the students were convinced that their research was not very scientific because genuine research has to discover something new. Moreover, collecting social data and carrying out economic calculations were not seen as 'genuine engineering'.

> *"It was not extremely scientific. It was a mere evaluation of a certain view on the problem and providing some suggestions for improvement. Genuine scientific work would not contain anything social; it would only promote technology. Actually I have never done that"* [Int. StudEE4, 4:36-4:50min].

As the following quotes show, some of the teachers conceptualize research in a similar way:

> *"Well, that was handicraft! They have recorded graphs; they have interpreted them, if one takes that as research, then one can say yes. But, where is the research? Where are the analyses of measurement results? It is a thin line between research and the daily role of an engineer"* [Int. TeachIE, L474-478].
>
> *"What's all this about research, I need equipment, I need an electron microscope, and I don't know what else! In the area in which we work – research means 10 million Euro and half of an enterprise behind me. As a social anthropologist this looks probably quite different"* [Int. TeachEl, L645-649].

Discussion

In a traditional view of engineering, the engineer's job is measuring and constructing technological solutions based on the rigorous mathematical processing of data. They usually work in the laboratory where they design and refine solutions to a given problem. The guidelines for a diploma thesis at Higher Colleges of Engineering in Austria reflect these characteristics of the engineer's job description: The assignment should comprise a problem for which a solution is found using substantial theoretical and practical knowledge and state-of-the-art technology. It may encompass situations which are not predictable and this will demand creative approaches.[9] Therefore, taking ecological demands or economic and legal constraints into consideration could be an important factor for design decisions. Although the user as a theoretical construct influences innovation, real-life contact with prospective users is usually not seen as an important part of the development process. A discussion regarding the social impact of technological systems and devices now and in the future is not a compulsory part of the engineering curriculum.

These principles guide engineering education and practice and are widely shared by teachers, students and departmental heads, not only in the Secondary Technical and Vocational School which participated in this project. These principles also guided the construction of the kindergarten building: Every facility was state of the art; the calculated energy parameters gave the building a low-energy status as defined by the legal regulations. However, to transform a low-energy building into a 'green building' or sustainable building "a careful understanding of relationships and patterns of interaction among those involved in the design, production and use of buildings" (Rohracher, 2005, p. 202) is necessary. The performance of energy-efficient buildings is an open-ended process and depends largely on pre-existing experiences and the social learning processes between providers (architect, municipality, engineers and construction companies), maintenance staff and users. This shifts the focus of the issues to be dealt with, in the context of the diploma thesis, from a purely engineering approach to a more inclusive approach, which reflects the sociocultural conditions of the use of technology.

Modelling the greening of the kindergarten building as a sociotechnical problem influenced the diploma thesis process significantly: The students did not construct devices, as is frequently done in the scope of a thesis. Instead, they proposed suggestions for ameliorating the users' indoor environmental comfort and the building's energy efficiency based upon rigorous measurements. However, communication with the users, the municipality, the maintenance staff and the other students involved in the project was of key importance for the research process.

Therefore, the research practiced in SOLARbrunn was not sophisticated cutting-edge technical research; it was rather applied research based on the actual experiences of engineers who are employed in small companies or are working as freelancers. Out in the field, engineers have to solve problems which are ill-structured at first sight, and they have to negotiate with their clients over needs and problems. They also have to adapt technological solutions and devices to the requirements of the users, and they have to instruct them how to use these devices. This approach caused some problems and questioned the commonly held beliefs of all project partners, the participants from the HTL as well as the head of the kindergarten, who was convinced at the beginning of the project that her voice was not important as she does not understand anything about technology.

The HTL project participants' feelings about some aspects of the project were particularly ambivalent, notably due to the high frequency of the meetings, the need to coordinate measurement designs, and most of all the need to combine technical and sociological research. On the positive side, the importance of the results for everyday life and the municipality as well as collaboration with the university were highly welcomed. The students learned a lot, but did they learn the right things, the right things for a 'skilled" engineer'? Was it genuine research that was carried out? For some of the teachers and department heads, it was not the 'lighthouse project' they had hoped for; they had difficulty assessing the students' successes and evaluating the merits of their work.

The project and the problems that it encountered raised points that questioned deeply held beliefs. It motivated teachers to think about future diploma thesis projects

9 www.htl.at/fileadmin/news/downloads/Diplomarbeit_Durchfuehrungsbestimmungen_HTL.pdf

which would be better adapted to the particular problems of the region and the future job prospects of those students who will not go on to study at technical universities or universities of applied sciences but who also want to start working in the region's SME's. A line of conflict ran between the "two cultures" which Charles P. Snow (1959) described, between arts and the social sciences on the one side and science and engineering on the other side; between positivism and interpretivism. These conflicting paradigms are deeply rooted in the beliefs of the project's participants, thus making sustainable technological development difficult. A cultural perspective which establishes a sharp line between methodical and discursive practices as used in the natural and social sciences generates a hierarchy, not only between academic disciplines but also between experts and non-experts. It narrows the view on 'genuine research', which is perceived as an elitist and expensive endeavour, thus impeding the participation of citizens in solving social problems related to climate change.

Yet, in the pragmatic approach of some of the engineers, the synthesis between the scientific and the social data is seen as quite a useful strategy for technological development. Questions about the role of social skills and the use of sociological methods were discussed. The teachers had to admit that they adhere to a hybrid engineering culture which neither mirrors the culture of engineering work in the field nor the culture of high-end basic and applied research. Moreover, the headmaster acknowledged the merits of emphasizing the three-pillar concept of sustainable development as a goal for school development.

Although a single project would not change what is a well-established educational structure with an excellent national and international reputation and a very specific culture, it can be seen as a considerable disturbance of the 'business as usual' approach and there is some hope that it has initiated a mental shift in some of the teachers and the students involved.

Conclusions

The most obvious finding which emerged from this analysis is in line with the analysis given by Donovan et al.: The objectives targeted and the practices developed at a HTL reflect to a high degree the "imperative perspective". In spite of the schools' success at placing graduates in the labour market, they often lack the required social skills for promoting sustainable development.

As the social and technical aspects of sociotechnical systems in general and low-energy houses in particular are inseparably interwoven, optimizing these systems is "only to a minor extent the search for enhanced technical solutions. What is much more challenging is the social embedding and the socially interactive process of designing, constructing and using" (e.g. Rohracher, 2001, p. 137) these buildings/technologies. Therefore sustainable development needs the interactive effort of various players to improve sociotechnical practices. In order to find resolutions to societal problems like climate change, experts and non-experts have to establish learning communities where the interests, attitudes, habits, values and perspectives of non-experts have the same status as those of the researchers and experts. Both sides have to develop a common understanding of the research problems but at the same time recognize that they have different interests and therefore have different perspectives on the specific research process. For a successful process, it is therefore important that a mutual understanding of interests and attitudes is negotiated in regular reflective meetings.

This study also suggests that to successfully integrate aspects of sustainable development into STEM education, a critical reflection of the culture of science and engineering plays a crucial role. The teaching-for-sustainability approach challenges the narrow image of engineering as a hard-science approach as well as the prototype of the 'skilled engineer'. As the dichotomy between 'hard' and 'soft' approaches also establishes a hierarchy between STEM experts and non-experts, reconsidering the culture of science and engineering also challenges the power relations/gender relations between engineering experts and laypeople. It therefore has the potential to initiate an organizational process that aims for a more realistic, more inclusive and less male stereotyped orientation in engineering.

A holistic approach to engineering comprising sustainable development shifts the emphasis away from constructing and building devices and more towards planning and adjusting sociotechnical systems built upon research-based analysis. It widens the possibilities of engineering activities and therefore has the potential to motivate a broader spectrum of young people to take up a career in engineering.

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