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Perspectives for International Engineering Education: Sustainable-oriented and Transnational Teaching and Learning

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Abstract

A global transformation from an economic towards a sustainable development is promoted by current policies from the United Nations and the European Union. Young engineers must be trained to anticipate the sustainability challenges for contributing bottom-up to a global sustainable development. Besides, they must be capable of performing in a more and more dynamic, transnational, and intercultural global working environment. Consequently, new perspectives for teaching and learning in higher engineering education are required, providing the competencies for coping with the sustainability challenges and for working within the dynamic global society. A transnational and project-oriented teaching and learning framework is outlined, which provides the future key competencies for young engineers. Based on this framework, the inter-university master course "European Engineering Team" is presented. The master course fosters the development of sustainable and entrepreneurial initiatives by leading the students through the development phases of a start-up company grounding on a sustainable innovation. A first evaluation of the master course shows, that most of the students' key competencies have been improved significantly.

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Keywords: Sustainable Development; Transnational Teaching and Learning; Higher Engineering Education

1. Introduction

A global transformation from an economic towards a sustainable development is promoted by current policies from the United Nations and the European Union. Young engineers must be trained to anticipate the sustainability challenges for contributing bottom-up to a global sustainable development. Besides, young engineers must be

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capable of performing in a more and more dynamic, transnational, and intercultural global working environment. Consequently, new perspectives for teaching and learning in higher engineering education are required, providing the competencies for coping with the sustainability challenges and for working within the dynamic global society.

Throughout this paper, perspectives for teaching and learning in higher engineering education are described taking into account these frame conditions. First, the state-of-the-art for Sustainable Development and Sustainable Innovations is discussed. Second, key competencies for young engineering professionals are derived and teaching and learning approaches in higher engineering education are analyzed. Third, a framework for the transnational and project-oriented master course "European Engineering Team" (EET, http://www.engineering-team.net) for training the key competencies is outlined. The master course aims at developing sustainable innovations based on a solution finding procedure as well as on a procedure for the integrated development of the product and business model. Last, the learning and teaching outcomes of the first cohort of the EET is reported and an evaluation of the course is presented.

2. Sustainable Development and Sustainable Innovations

Sustainability is considered to be the key driver for innovation in the 21st century [1]. The concept of sustainability-driven innovations was firstly introduced by Keeble et al. [2]. Adams et al. introduced a three-stage model for sustainable-oriented innovations (SOI) [3]. The development of Sustainable Innovations is planned and controlled by entrepreneurs. In this context, the term of Sustainable Entrepreneurship was coined by [4], [5], and [6]. The development of innovations can be structured into an early and late stage. The early stage, also known as the Front End of Innovation aims at finding and specifying a first idea for the innovation and is characterized by a fuzziness and uncertainty of the development process. The development process itself can be structured into a task definition phase followed by a generation and selection of solution ideas for the task [7]. Methodologies for the early stage of the innovation development are e.g. the TRIZ methodology [8] or Design Thinking [9]. The late stage of the innovation development addresses the more structured phases for the detailed design of the innovation. Elements of sustainability can be integrated into the innovation during the early and late stage of the development. The integration of sustainability elements during the early stage of the innovation development can be realized during the generation of solution ideas as presented by [10], [11], or [12]. For the selection of solution ideas, different approaches for their evaluation are presented by [13], [14], or [15]. In this context, the Life Cycle Sustainability Assessment (LCSA) is described as most viable framework for the evaluation of ideas, products, and processes [16]. For integrating sustainability elements during the later stage of the innovation development, approaches addressing the business model and product development can be distinguished. [17], [18], [19], and [20] established concepts, methods, and tools for enabling the development of sustainable business models. [21] and [22] describe concepts for the sustainable product development.

The development of sustainable innovations by young entrepreneurial students should be provided as a key competency in higher engineering education. By doing so, the future young professionals are aware of the sustainability challenges and are capable to contributing bottom-up to a global sustainable development.

3. Teaching and Learning Competencies in Higher Engineering Education

The more and more dynamic, transnational, and intercultural working environment in Europe coined by new social, economic, and environmental trends set new requirements for teaching and learning in higher engineering education. In terms of the required competencies for young professionals, different organizations propose similar sets of relevant competencies. The UNDP promotes leadership, innovation, people management, communication, and delivery as core competencies [23]. Learning to learn, social and civil responsibility, initiative and entrepreneurship, cultural awareness, and creativity are horizontal key competencies defined by the European Commission, which is also highlighting mobility as an essential competence [24]. In terms of teaching and learning methodologies in higher education, John proposes a student-centered, project-oriented approach for an effective learning program [25]. The concept of experimental learning presented by Kolb and Kolb provides an effective and

commonly-used teaching and learning approach [26]. It is based on a learning cycle of reflecting on the impacts of performed activities and subsequently deriving and implementing measures for improving these activities. For the specific implementation of effective teaching and learning concepts in higher engineering education different concepts are being discussed. Learnstruments are objects which automatically demonstrate their functionality to the learner in order to expand the competencies of the learner in the economic, environmental, and social domains of sustainability. They provide adequate learning goals and support the learner in achieving these goals by the utilization of new technologies [27]. Learning factories provide a learning environment specified by a process, setting, product and a didactical concept for an experienced-based learning in a partial model of a real factory [28]. Besides these more on technological artefacts orientated teaching and learning concepts, project oriented teaching and learning concepts play an important role in higher engineering education. Especially, transnational and project-oriented concepts seem to provide the future key competencies for young professionals by addressing particularly social and self-competencies, e.g. communication, cultural awareness, leadership, team work, or mobility [29]. Project-oriented and transnational concepts in engineering education consist of virtual and presence elements for teaching and learning. Different concepts are described by [29], [30], or [31].

For providing the required competencies for young professionals in engineering, transnational and project oriented concepts need to be developed, aiming at an entrepreneurial objective by developing Sustainable Innovations and additionally providing the important social and self-competencies.

4. Framework for the European Engineering Team (EET)

The development of the Sustainable Innovation throughout the EET addresses specific course elements for training the professional, methodical, social, and self-competencies of the students (Table 1). The important teaching and learning phases of the master course include a project working phase based on the innovation development and including four one-week presence phases at the partner universities. Virtual cooperation and collaboration of the students on the basis of online tools is applied between these presence phases. An e-learning phase is implemented providing relevant lectures.

Table 1. EET Course Elements for Training the Key Competencies

Competencies		EET elements for training the competencies	
Professional and methodical competencies	▪ Entrepreneurial mind-set ▪ Knowledge about procedures, methods, and tools for finding solutions, for sustainable value creation, for product and business model development	▪ Project topic focusing on the development of a sustainable innovation and building a start-up company ▪ E-Learning lectures ▪ Application of specific engineering methods and tools
Social competencies	▪ Intercultural competencies ▪ Capacity for team work and people management ▪ Communication capability and persuasive strength ▪ Willingness to resolve conflicts	▪ Intercultural and interdisciplinary team composition ▪ Project work in small teams and with work packages ▪ Periodic presentations and reports of the work progress
Self-competencies	▪ Cross-border mobility ▪ Leadership and self-confidence ▪ Learning to learn ▪ Engagement and reliability	▪ Mobility phases at each partner university ▪ Self-guided work in an intercultural and interdisciplinary team ▪ Presentations and discussions in teams

The framework for teaching and learning in the master course follows the idea of experimental learning. For supporting the development of Sustainable Innovations, Kolb's learning cycle for experimental learning has been combined with a procedure for solving problems and finding solutions, which is following the natural problem solving behavior of humans [32]. As result, a cycle evolved which offers a problem-solving procedure within the level of single process steps for the development of a sustainable innovation and simultaneously provides a high teaching and learning efficiency throughout the master course. This logic with an emphasis on designing experiments and running tests supports the development of innovations in an environment of extreme uncertainty. The sequence of important process phases of the innovation development for the EET follows the Diamond-Model

[32]. The Diamond-Model offers a procedure for the integrated development of the product and business model for the startup. Figure 1 provides a structure of the teaching and learning framework for the EET.

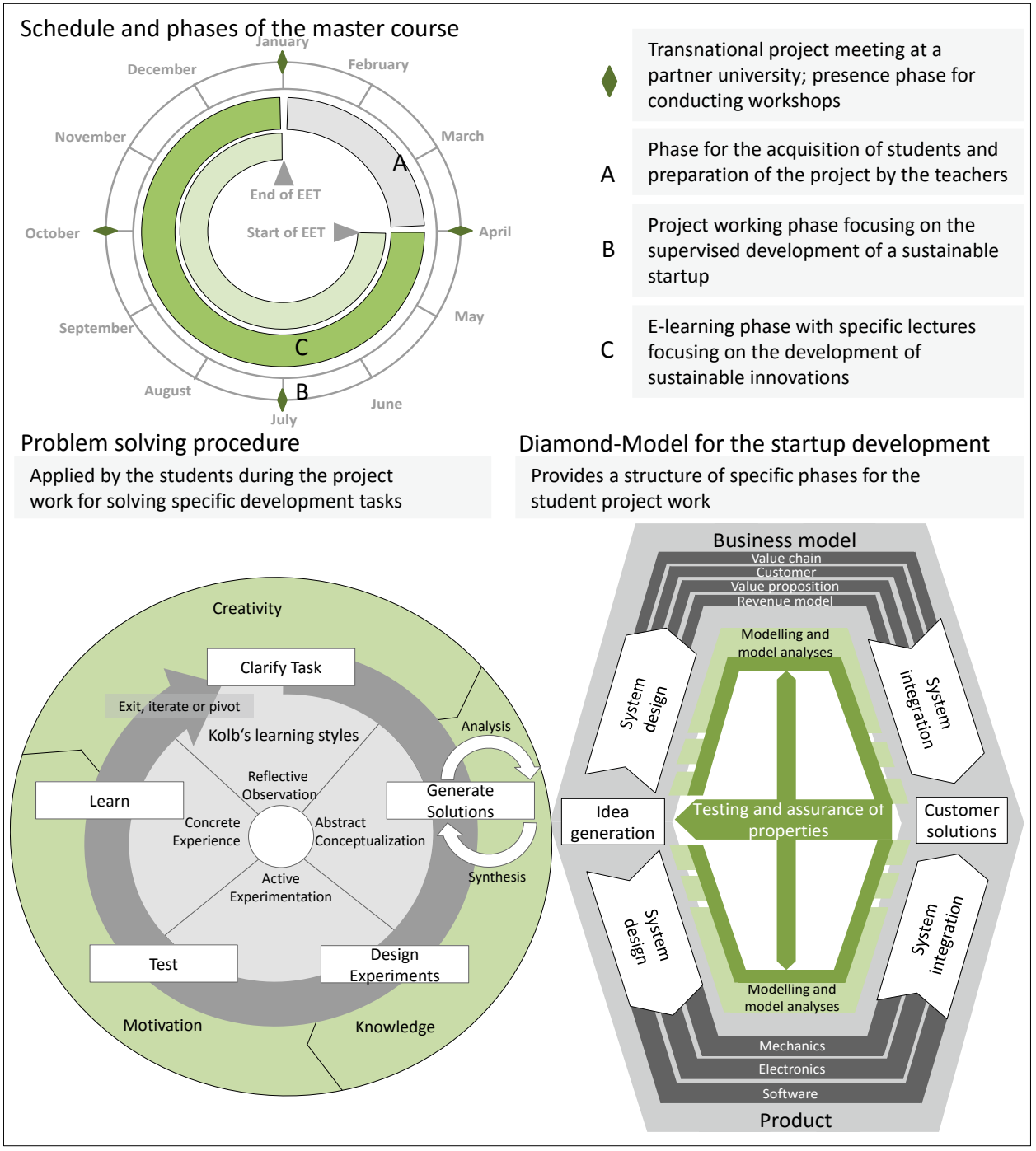

Fig. 1. Framework for Teaching and Learning in the EET

5. Learning and Teaching Outcomes of the first Cohort of the EET

5.1. Product and Business Model Development of the Sustainable Innovation

The EET chose "excessive municipal solid waste and its inefficient disposal" as the overreaching field for the innovation. This field is related to the twelfth Sustainable Development Goal of the United Nation, which aims to ensure sustainable consumption and production patterns. Sustainable growth and development requires, among others, the reduction of waste generated throughout the production and consumption processes [33]. For analyzing potential problems in this innovation field, the EET formed four working groups which specifically dealt with sub-fields: food waste, packaging waste, city waste management, and home waste management. Each working group developed specific solution ideas for innovations in their specific sub-field. Subsequently, the EET evaluated the sub-field solutions and decided to focus on waste prevention in the logistics supply chain with to complementary innovation ideas: a thermal cover (presented in [34]) and the Anchora pallet, discussed in the following.

In 2014, 162.6 kg of packaging waste was generated in average per inhabitant in the EU. In order to improve the end-of-life phase for packaging waste, a directive of the European Parliament and Council increased the target rate for its reuse, recovery and recycling. This led to significant improvements in the recovery and recycling rates in the EU since 2009 [35]. However, a further increase in these rates, a stronger focus on reuse, as well as a decrease in the amount of packaging waste can significantly improve the quality of life of the EU citizens and contribute to the sustainable consumption of resources. On the basis of current packaging approaches, new sustainable solutions should be developed.

For identifying first customer needs in the field of sustainable solutions for packaging, the EET carried out an online survey and interviews with different companies. These activities revealed that the commonly used Euro pallets have only one size and are relatively cost expensive. Half-sized pallets are cheaper than regular sized pallets, more adaptable, and space saving. However, in terms of a customer demand for smaller sized pallets, these pallets are made for single-use only, leaving the end customer with the task of disposal.

In conclusion, a solution idea for a novel sustainable pallet system was generated: the Anchora pallet. The pallet system should be customizable and adaptable to the costumers needs and should allow multiple use phases. The product and business model development followed the methodology of the Diamond-Model.

In terms of the product development, only the mechanical domain was relevant for the development of the Anchora pallet system. Based on the customers' needs, first product requirements and functions had been derived. The requirements cover the set of specific properties for the product. The functions describe the fundamental product functions and characteristics for fulfilling the product properties. For the product functions, specific solutions had been developed and realized in form of a design for a first virtual prototype. This prototype was subsequently manufactured and assembled in order to test and validate the functionality of the hooking mechanism between the quarter pallets. In a second iteration, the design of the first prototype was improved and led to the final design of the Anchora pallet. In terms of the business model, the customers, value proposition, value chain, and the revenue model had been developed. For this purpose, a vision for the business model was created by the students. The visons specifies the idea of the innovation as well as fundamental ideas and main requirements for the business model in general. Following this initial vision, different hypotheses for the customer segments, value proposition, value chain, and the revenue model were created. Hypotheses are first assumptions for shaping theses different domains of the business model. For the hypotheses, the students subsequently developed specific solutions which have already been proven in entrepreneurial practice. In order to test the different solutions, the first business model was presented to experts in the field of logistics and supply chain management during a pitch event. Based on the feedback during the pitch, a final archetype for the business model was developed. For the final business model, different use cases for potential first customers as well as an implementation plan was derived. The outcomes of the product development as well as of the business model development are presented in Figure 2.

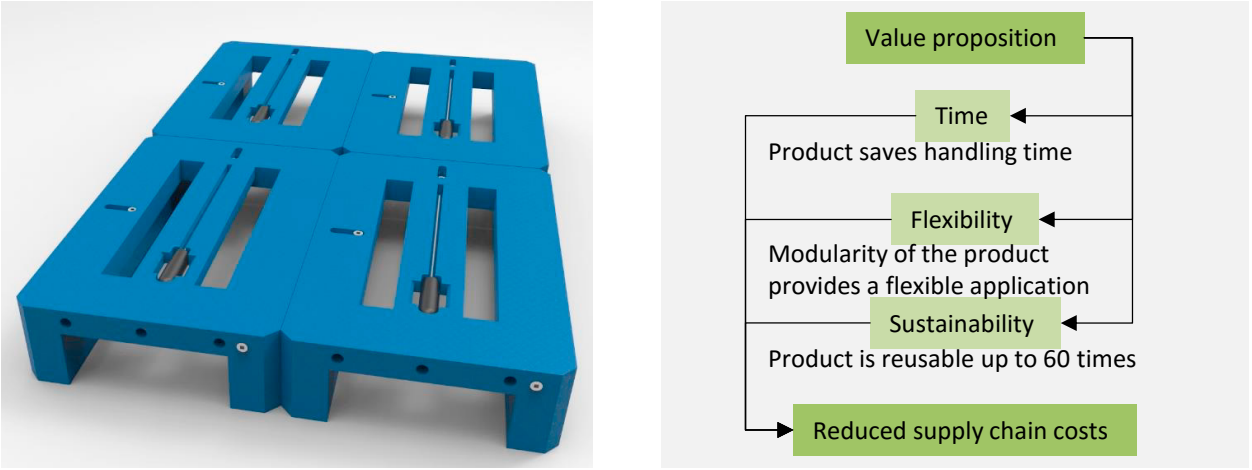

Fig. 2. Virtual prototype of the Anchora pallet system (a) and configuration of the value proposition (b)

5.2. Evaluation of the course "European Engineering Team" and its framework

For evaluating the teaching and learning effectiveness of the course and its underlying framework, three anonymous surveys were provided to the 13 students during the progression of course: a first survey at the beginning of, an intermediate survey in the middle, and a final survey after completing the course. The surveys aimed to track the development of the professional, methodological, social, and self-competencies of the students on a scale from 0 (very poor) to 10 (excellent). Within Figure 3, the results of the first and final survey are compared. In conclusion, most of the students' competencies have been improved significantly. Especially, the professional and methodical competencies in terms of startup development, process development/ design, and product development/ design indicate a substantial improvement. This improvement also applies for the social competencies in terms of presentation and mediation, communication, as well as conflict resolution, and for the self-competencies in terms of self-confidence/leadership and flexibility/ adaptability. Moreover, opportunities for improving the master course have been identified: the competency development in the field of sustainability and problem solving/ innovativeness will be emphasized for future cohorts.

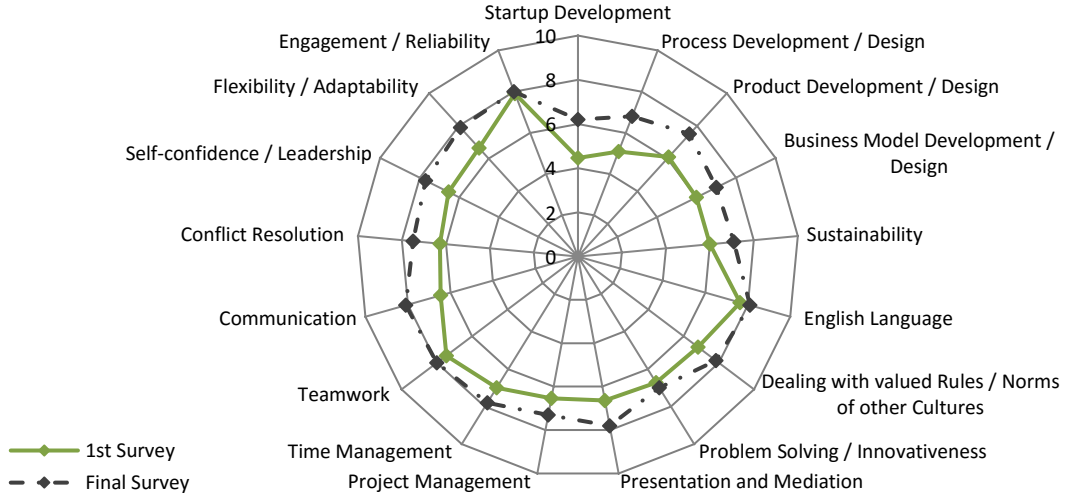

Fig. 3. Results of the first and final student survey for evaluating the teaching and learning framework

6. Summary

For coping with the challenges related to a global sustainable development as well as for fostering a sustainable transformation following the United Nation Agenda 2013, new approaches for teaching and learning in higher engineering education are required. Young engineers must be trained to anticipate these challenges and to contribute bottom-up to a global sustainable development by developing sustainable innovations. Besides, these young professionals must be capable of performing in more and more dynamic, transnational, and intercultural working environment in Europe. Perspectives for teaching and learning in higher engineering education have been described for these frame conditions:

Key competencies for young engineering professionals have been derived and teaching and learning approaches in higher engineering education have been analyzed. Transnational and project-oriented concepts seem to provide the future key competencies for young professionals. A framework of the transnational and project-oriented master course "European Engineering Team" for training the key competencies has been outlined. The master course aims at developing sustainable innovations by applying a problem solving procedure based on Kolb's learning styles and by following a Diamond-Model for providing a structure of the start-up development. The learning and teaching outcomes of the first cohort of the EET have been described for the product and business model. An evaluation of the master course showed that most of the students' competencies could be improved significantly.

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