Sustainable Energy-Efficient Living – A First-Year Project-Based Workshop For Energy Engineers

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SUSTAINABLE ENERGY-EFFICIENT LIVING – A FIRST-YEAR PROJECT-BASED WORKSHOP FOR ENERGY ENGINEERS

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ABSTRACT

For many engineering students a lack of study motivation plays a significant role in their drop-out process (Heublein 2014). Therefore, students' motivation to study should be encouraged as early as possible. A proven strategy for increasing the study motivation is the integration of project-based learning (PjBL) in the course of studies (Kokotsaki et al. 2016).

This paper introduces a PjBL-workshop concept which was developed for first-year energy engineering students at a university of applied sciences in Germany. During

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this one-semester workshop, the students are working weekly as student trainees in a fictitious engineering office. Guided by the teacher as the project lead, the students are developing a concept for integrating various renewable and sustainable energy systems in a single-family home. Each week they take on subtasks of a different work package supporting other employees of the engineering office. During their time as student trainees they have to face authentic engineering challenges like constructing a photovoltaic plant or dimensioning a battery system. Progress and results are documented in a project journal.

First insights of initial implementations of the concept led to a closer focus on the aspect of the perceived authenticity of the PjBL-setting (engineering office) by the students. Therefore, besides the conceptual and contentual design of the workshop, this paper will also address the creation of the authentic setup of the engineering office.

Future research in this ongoing study will examine the influence of the perceived authenticity on various aspects such as the motivation to study.

1 INTRODUCTION

The demand for well-trained engineers has never been higher. However, institutions of higher education are still struggling with increasing dropout rates in engineering study programs. As a main reason for their dropout in the first semesters many students state a lack of motivation to study (Heublein 2014).

One strategy to counteract these dropout rates can be the integration of the student-centred (Kokotsaki et al. 2016) approach of project-based learning (PjBL). This method is widely used in engineering education (Chen et al. 2020), provably increases the students' motivation to study and provides many benefits and engineering skills for students, like enhanced critical thinking, independent learning (Frank et al. 2003) and improved problem-solving skills (Harmer and Stokes 2014).

In order to promote the study motivation as early as possible, PjBL should be used from the beginning of the study program. In this paper, a PjBL-based workshop for first-year energy engineers will be introduced. Therefore, the challenges of the PjBL implementation, the framework and the structure of the workshop-concept will be described. An overview of the content design of the workshop will be presented afterwards. In addition to the conceptual and content design, this paper will also focus on the design of the authentic setting. Finally, an outlook on the next steps in this ongoing study is provided.

2 PROJECT-BASED LEARNING

Defining PjBL is challenging due to different understandings of the term in different countries and disciplines (Harmer and Stokes 2014). Sometimes it is used similarly or interchangeably with problem-based learning (PBL) (Harmer and Stokes 2014). Differences and similarities between these two approaches will thus be discussed later in this paper.

PjBL can be considered as a particular type of inquiry-based learning (Kokotsaki et al. 2016), as many elements of PjBL are derived from this method (Frank et al. 2003). Inquiry-based learning itself is based on the constructivist teaching approach, according to which students learn concepts or construct meaning through their interaction with others and their world (Frank et al. 2003). Therefore, three constructivist principles are forming the fundament for PjBL (Kokotsaki et al. 2016): (1) learning is context-specific, (2) learners are involved actively in the learning-process and (3) learners achieve goals through social interaction and sharing of knowledge and understanding. From these principles, seven main characteristics of PjBL can be deduced.

2.1 Main characteristics

In accordance with principle 1, the context of learning for PjBL is provided through *authentic driving questions* within real-world problems (Kokotsaki et al. 2016), which form the fundamental element of the project. These complex and open-ended problems are often identified by the teacher and further developed by the students during their investigations (Harmer and Stokes 2014). Essential for the approach is, that the outcomes or solutions for the problems are not predetermined, so that the students have a flexibility in their problem-solving process (Harmer and Stokes 2014).

During their investigations the students are involved actively in the learning process (principle 2) (Kokotsaki et al. 2016). Active here means *learning by doing*. The students' role changes from the traditional, passive listener to an active maker (Harmer and Stokes 2014). Hands-on experience in practical projects strengthens the connection and identification with the faculty and gives an informed view of the target profession (Harmer and Stokes 2014).

To take more responsibility for their own learning, the projects are mainly student-driven (Kokotsaki et al. 2016). With a high degree of *autonomy*, the approach leaves space for developing own methods and procedures (Harmer and Stokes 2014).

Whereas student independence increases, the teacher moves more into the background and acts as a facilitator or a mentor during the project (Kokotsaki et al. 2016, Frank et al. 2003, Harmer and Stokes 2014). As often found in the literature the shift of the teachers' role can be described as from a 'sage-on-the-stage' to a *'guide-on-the-side'* (Harmer and Stokes 2014). The teachers' task is to create a contextualised learning environment, that allows students to construct their own knowledge (Frank et al. 2003), while balancing their need for support and autonomy (Harmer and Stokes 2014).

The third principle indicates the need for social interaction and collaboration in the learning process (Kokotsaki et al. 2016). PjBL is based on *team work* where students learn important skills like interacting, communicating and planning as a preparation for their future everyday engineering life (Harmer and Stokes 2014).

PjBL-projects often either cross or combine multiple disciplines (Harmer and Stokes 2014). *Interdisciplinarity* enables a differentiated view of the boundaries of one's own discipline and the points of connection with other disciplines.

One of the most distinguishing features of PjBL is the creation of an *end product*, which drives the whole process of planning and realisation of the project (Harmer and Stokes 2014). The types of outputs or artefacts vary from real products (Frank et al. 2003) to presentations and reports (Kokotsaki et al. 2016). The end products are usually shared with an authentic and appropriate audience, like fellow students or teaching staff (Harmer and Stokes 2014).

2.2 PjBL vs. PBL

The construction of an end product or concrete artefact is not only the most signifying element of the PjBL approach, it is at the same time the feature that distinguishes it the most from the related PBL approach (Kokotsaki et al. 2016).

Both approaches are based on similar principles with focus on problems with relevance to the real world. The two of them are working with collaboration of the students (Kokotsaki et al. 2016) and facilitating teachers. The main difference between them is, that PBL primarily concentrates on the process of learning (Kokotsaki et al. 2016) or producing a plan or a strategy (Harmer and Stokes 2014), while PjBL focusses on the creation of a real end product (Kokotsaki et al. 2016) or carrying out a plan (Harmer and Stokes 2014). The challenge is furthermore, that these two terms are sometimes used equally, distinguished or combined, depending on the discipline, the country or the regarded research group (Kokotsaki et al. 2016). In this paper, these two approaches are considered as similar but distinct.

2.3 Challenges

Implementing PjBL with all its elements is challenging. In the literature, a wide range of challenges is reported. Chen et al. (Chen et al. 2020) identified several challenges on individual, institutional and cultural level for students and teachers, the most on the individual level. For the teachers, a lack of training as facilitators and the choice of assessment is the main challenge. For the students, it is the lack of teamwork skills, self-learning skills and project management skills that causes problems (Chen et al. 2020). Harmer and Stokes (Harmer and Stokes 2014) and Kokotsaki et al. (Kokotsaki et al. 2016) each present a set of recommendations to master these challenges.

2.4 Authenticity in PjBL

Furthermore, Strobel et al. (Strobel et al. 2013) address a concern regarding the design of authentic learning environments, like in the PjBL approach. ‘What is considered authentic to the teacher is not necessarily authentic to the student’ (Strobel et al. 2013, p. 144). In addition to that, the term authenticity is ‘often used without reflection or clear definition’ (Strobel et al. 2013, p. 144).

According to Bialystok (Bialystok 2017), in order for something to be perceived as authentic by the students, it does not have to correspond to the actual reality, but to what students assume to be their personal reality. Therefore, it will be important and necessary to know the students' personal reality regarding the project scenario or the project environment in order to be able to provide them with an authentic experience during the project.

3 PROJECT-BASED WORKSHOP

The following chapter introduces a workshop designed according to the characteristics of PjBL presented in section 2.1. First, the framework conditions for the workshop are explained, afterwards the implementation of the PjBL elements is described in detail.

3.1 Framework conditions

The PjBL-workshop is part of a mandatory first-semester introductory course for freshmen of two energy engineering study programs at a university of applied sciences in Germany. The study programs share basic courses and specialise towards energy systems or energy information technology. The course consists of a lecture (3 hours per week) and the weekly practical PjBL-workshop (2 hours per week) and has 6 ECTS. The semester lasts 15 weeks, whereby 2 weeks are provided as self-study weeks and are thus omitted as lecture weeks. The grade for the course is composed of 70% of the assessment of the lecture and 30% of the workshop, what will be described in detail in the next section. The lecture will not be discussed further in this paper.

During the winter semester 2020/2021 the workshop was performed as a reduced online version due to the pandemic situation. The course started with 40 active participants and finished with 35. In the winter semester 2021/2022 the workshop could be carried out in presence in its intended version. At the beginning of the semester, the number of participants was 34 students, which dropped to 25 by the end of the semester. The reason for dropping out of the course was mainly due to dropping out of the entire degree programme or changing the degree programme. The attendants of both years were mainly first-year students, a small amount was from higher semesters.

3.2 Implementation of PjBL

The story for the authentic scenario in this PjBL-workshop begins with a young couple, who bought an old single-family home from the 1960s. They hire an engineering office to develop a concept for the integration of renewable and sustainable energy systems to their new house, as they want it to be fully renovated and modernised. Working as freshmen student trainees in the engineering office, the students are involved in this new project. By taking on subtasks of different work packages every week, they support other employees of the fictitious office.

The described authentic driving question of this project is identified by the teacher, who acts as the project lead here. The project is already pre-structured into work packages. This intends to give the inexperienced first semester students in particular a framework or common thread for their project. However, in compliance with the PjBL characteristics the outcomes of the work packages are not predetermined and the students have space for their creativity and can experience different tools and methods to solve the driving problem. They are involved actively in the process of developing and designing the sustainable energy system concept, which represents the intended end product of the project.

Each workshop session starts with an opening by the project lead (teacher), where the tasks and sub driving questions for the current work package are presented. Working material is provided through the online learning platform Moodle. Tools and software needed for the next session are introduced in videos, so that the students can prepare themselves in advance. After the weekly introduction, the students work mainly autonomously in teams of three. The teacher takes on the passive role of a facilitator and provides support if needed.

The project is divided into three phases. Table 1 gives an overview of these and their corresponding work packages, including the number of weeks dedicated to each work package. Further, the used methods for each work package are described.

In the preparation phase, the students get an introduction in skills they need for their work in the engineering office. They are already working in teams, but the composition of the teams is still flexible and vary each week in this phase. This serves the purpose that the students should first get to know each other better before forming fixed teams, since they are new to the university. The students learn how to organize themselves and communicate within their teams and how to communicate with the project lead. They write a guideline about the characteristics of scientific literature, how to find and identify it. Furthermore, they deal with the appropriate documentation of results and work progress.

From the fourth week onwards, the students form fixed teams of two to three by their own choice, which remain unchanged until the project ends. The execution phase starts, in which the actual project is processed. Each team member documents their teams project progress and weekly results in a personal project journal. In addition to that the students also write down personal reflections of the project process in their project journal. At the end of the week, the journal entries are uploaded to the Moodle platform and reviewed by the project lead. Review criteria are completeness, technical correctness in the documentation and accuracy of the notes as well as the focus on the project aims. The personal reflection part is not subject to a separate assessment, but should be structured, self-reflective and critical.

During the project execution phase, the students work on four different work packages of interdisciplinary topics. Each team will work on the same work packages. The teams' project outcomes, nevertheless, will differ since each team will make its own decisions and use its own approaches.

Table 1. Content and methodological structure of the workshop

Project phase	**Work package**	**Methods and social forms**	**Number of weeks**
Preparation	Communication for teamwork	Group discussion, plenum discussion	1
	Research on scientific literature	Literature research, report writing	1
	Documentation of work progress	Investigation of negative examples	1
Execution	Photovoltaic plant	Inquiry-based learning with simulations, software usage	3
	Battery system	Literature research, choices based on solid justifications	1
	Solar thermal system	Visit of a real plant	1
	Pellet heating system	3D-designing, 3D-printing, peer review	3
Completion	Presentation of the energy concept	Oral team presentation	2

The project begins with the design of a photovoltaic plant for the house. First, the students investigate the solar orbits during different seasons by simulations to understand how to find out the perfect position for the plant on the roof. In the following two weeks the students use the designing software PV*SOL to plan the actual photovoltaic plant. The next work package deals with the dimensioning of the battery system. Here the students examine different types of battery technologies and should give a recommendation for the clients' house, based on literature research. After finishing the electrical supply for the house, the students plan the thermal supply. A solar thermal system is to be installed to heat the domestic hot water. The students visit the solar thermal system of the university and learn about the elements of the system and their functionality. Afterwards, they have to design a system diagram for the clients' house, in which they have to apply the newly gained knowledge from the inspection of the actual plant. In the following three weeks, the students plan a storage room for pellets to be used in a pellet heating system. In this work package, the students build a ramp structure to slide the pellets to the exit of the pellet room towards the heating. The work package includes designing the ramp in Autodesk's 3D software environment Tinkercad, creating it in a 3D printer, and testing and evaluating one's own ramp and that of another team.

In the last phase, the project is concluded by a team presentation in which the students present their elaborated results and thus their developed sustainable energy concept for the house as their end product of the project. The audience consists of the other teams, the project lead and other members of the engineering office, represented by teaching staff of the university. The engineering office members and the project lead evaluate the presentations of each team and decide which concept is finally realized and presented to the clients. For the assessment of the whole workshop, team and individual evaluations are combined. The grade is composed of 50% each of the evaluation of the team presentation grade and the weekly project journal grade.

In this implementation of PjBL, all the main characteristics presented in section 2.1 have been successfully integrated. Nevertheless, the point of interdisciplinarity might not necessarily be implemented as it was originally intended. The workshop is composed of work packages that all come from the field of energy engineering. However, energy engineering itself is interdisciplinary and consists of many different disciplines, such as electrical and thermal energy generation, distribution and storage, different sorts of renewable energies and energy efficiency. Therefore, the workshop demonstrates the interdisciplinarity of energy engineering so that first-year students get an orientation in their chosen field and a first impression of the interdisciplinary challenges they have to face during their studies and their further professional life as energy engineers.

4 EVALUATION AND RESULTS

4.1 First survey and interviews

After the first realisation of the workshop in winter semester 2020/2021, the students took part in an online evaluation consisting of a questionnaire. The intention of the evaluation was on finding out how the students assess the implementation of the PjBL elements, the engineering office scenario itself and the learning materials from their point of view and where they see potential for improvement. Additionally, five students had been chosen for a guided interview to obtain more detailed insights of the evaluation of the PjBL concept. The results showed a high acceptance of the concept and the idea of the engineering office setting. The level of difficulty of the work packages was assessed as mostly appropriate. The students could well imagine that they would have to complete such tasks as real student trainees, since they never had to bear the complete responsibility for the work package alone, but rather work alongside the permanent employees from the engineering office. The above-mentioned challenges for students could be also mastered well mostly. Especially the lack of teamwork and project management skills was well supported during the preparation and execution phase. The students were motivated and enjoyed their creative space during the project.

According to section 2.4 one main challenge identified was the difficulty in implementing the authentic learning environment. This was also apparent in the interviews. The engineering office setting was not always present and authentic for the students. Sometimes they forgot that they had to take on the role of student trainees. The change from the participant in a university course to an employee in an engineering office was occasionally difficult for them. Moreover, it was not always easy to see the teacher in the role of the project leader rather than the university member and rater.

4.2 Exploratory survey on student's reality of an engineering office

To enhance the understanding of the students' imagination and mental picture of an engineering office, a written survey with open questions within a questionnaire was conducted at the beginning of winter semester 2021/2022. Uninfluenced by the following confrontation with the designed engineering office setting in the workshop, the students should describe how they imagine an engineering office, what they associate with that term and what experiences they might already have gained. The questionnaire contained questions like:

'*Name the first 3 words you associate with the term engineering office.*'

'*How do you recognise an engineering office? What do you think is typical for an engineering office?*'

'*Have you worked in a real engineering office yourself or do you know someone who works or has worked in an engineering office?*'

The majority of the students have never worked in an engineering office themselves or know someone who does. Mostly, they described typical elements of offices for architects or civil engineers, like open space offices and technical drawings pinned onto the walls. These elements are in contrast to typical classrooms of universities.

The results of the survey will therefore be used to create a more suitable learning environment for the PjBL-workshop, which will be designed as the students imagine an engineering office and will look less like a classroom. The intention is to overcome the classic teaching patterns and to literally give the new roles of students and teachers a new room to develop.

5 CONCLUSION AND OUTLOOK

This paper introduced a PjBL-workshop for freshmen energy engineering students with details of its content and methodological structure. As already mentioned by Strobel et al. (Strobel et al. 2013), the main challenge for the implementation also was identified as the creation of the authentic problem-solving environment, since what is authentic for students is not necessarily what teachers consider it to be. Although the majority of the participating students have not yet had any direct or indirect experience with an engineering office, they already have an image of it. Influences of this on their perceived authenticity of the PjBL-setting will be investigated in the further study. This ongoing study will also examine the effect of the perceived authenticity of the PjBL-setting on factors like the study motivation, the intrinsic motivation for the project or the individual and situational interest for the project topic.

Strobel et al. (Strobel et al. 2013) additionally pointed out, that there is a need for robust models and operational definitions of authenticity, especially in engineering education. Investigations regarding the effects of authenticity on learning outcomes are needed.

Therefore, in further steps of this study, a model of perceived authenticity, including an operationalisation, will be developed on the basis of the presented PjBL-workshop concept.

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