TEACHING AI COMPETENCIES IN ENGINEERING USING PROJECTS AND OPEN EDUCATIONAL RESOURCES

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ABSTRACT

A major challenge in engineering education is to empower students to use their acquired technical skills to solve real-world problems. In particular, methods of

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Artificial Intelligence (AI) need to be studied as tools in their respective application contexts. This puts pressure on university lecturers concerning the didactical design and elaboration of a course, and requires them to move towards a practice-based learning approach. Moreover, working on real-world problems leads to uncertainties for the lecturer and their students. Before and during the course, it is not always clear which methods will be used to solve the problem, respectively which competencies the participants need to acquire.

Therefore, we propose to combine two established approaches: a project-based learning approach and the use of digital, curated learning content provided by Open Education Resources (OERs). We hypothesise that a practical study project solving a real-world problem using a combination of OERs and project-based learning is beneficial to AI education. Furthermore, we show implementations of our concept in three different courses.

The first results indicate that student-centred tasks lead to high intrinsic motivation. At the same time, lecturers have to deal with a modified and extended role: They are no longer the broadcaster of knowledge but rather a guide within the learning process. Using the combination of OERs and project-based learning, the courses are attractive and exciting for students and lecturers without becoming unmanageable.

1 INTRODUCTION

1.1 Motivation

The use of Artificial Intelligence (AI) as a tool and assistance is growing and requires engineers to enhance their digital skills including data and AI competencies. Thus, higher education institutes must complement current engineering curricula with these competencies.

Current approaches to teaching AI are mostly algorithm-oriented, meaning that the learning goal of a unit is teaching a class of algorithms in one particular context, whereas earning the competence of choosing and adapting known methods to a given real-world problem is neglected most of the time. Thus, students first get to know an approach or a methodology to solve problems in a class and the transfer to real-world problems is only a minor aspect. This is not a sufficient preparation for real-life situations, where engineers are required to handle complex situations “on the fly” [1]. In our volatile world independently acquiring context-specific knowledge on demand (often called “ad-hoc” learning) becomes a key competence. This cannot be achieved through the classical “stockpiling of knowledge” but only through learning by doing [2].

With AI as a tool, it is even more important to teach it in its applied context using real-world problems and projects [2]. However, designing a practice-based university course that is interactive and stays up to date with the latest trends remains difficult. Moreover, integrating projects in courses leads to situations where it is not always clear which methods will be used to solve the problem and which competencies the participants need to acquire for them.

In the following, we discuss how a practical study project solving a real-world problem with AI tools can be implemented using a combination of project-based learning (PBL) and Open Educational Resources (OERs). We hypothesise that the use of OERs in PBL can combat uncertainties in the process of a project for students and teachers. Moreover, we argue that the use of OERs in a PBL setting changes towards an on-demand use, which in return changes the role of the lectures. To support our hypotheses, we implement the idea in three different courses and provide the first lessons learned. We discuss our initial findings on the changing roles of lecturers and their effect on students and give an outlook on the next steps.

1.2 Project-based Learning

The idea of practice-based learning is not new and was proposed in multiple forms, one of the most prominent being project-based learning (PBL). PBL means dealing with a subject matter based on a concise, self-contained, project-based task, that is solved independently. The focus is not only on finding an original solution but also on planning and conducting the solution process itself, including compiling and acquiring the relevant information and materials.

The PBL approach is suitable wherever the application of knowledge to a practical problem is involved. Thus, it is extremely helpful when dealing with the complex methods and approaches that AI poses [3]. In comparison to traditional engineering classes, where a given problem is solved with given methods, PBL requires students and lecturers to deal with uncertainties. These are similar to the uncertainties that will occur later in real life: at the beginning, it is not entirely clear whether the project will work out as expected and which approaches will be successful.

The decisive advantage of PBL as an instructive approach lies in the direct and intuitive learning experience for students. Once learners have gone through a PBL solution and implementation process, it often does not only have a positive effect on their motivation. Knowledge acquired through PBL is usually also remembered better due to the high degree of personal involvement. The learning process is more intense and practical pitfalls that are missed in purely theoretical considerations can be (fore)seen and dealt with by employing a PBL application [4].

For lecturers, the use of PBL approaches poses multiple challenges. First, methodological and didactic planning and organisation are more complex and time-consuming as a wide range of material has to be made available to address the uncertainty of the projects and the heterogeneous learning preferences. The project outcome and possible solutions are not always clear in the beginning and lecturers have to take into account heterogeneous learning preferences and states of knowledge of their students. Second, for lecturers in the field of engineering who want to incorporate AI applications into their teaching in order to convey AI skills, there is the additional challenge of integrating knowledge from other disciplines. Third, students need support for planning projects, adjusting plans when necessary and developing solutions.

Students, as well as lecturers, have to deal with an immensely increased complexity and a general openness of the process when it comes to project-based learning. Yet the chances for fostering capacity-building outweigh these challenges. In the

following, we demonstrate how the integration of OERs in teaching can support project-based learning, especially with respect to interdisciplinary AI competencies.

2 APPLICATION-ORIENTED TEACHINGWITH PROJECTS AND OERS

2.1 Integrating OERs in Teaching

OERs are learning media that are free to use. Usually, the material is digital and developed by others. OERs can be both individual materials such as texts, images, or videos on a specific topic, as well as curated content that is compiled into entire courses.[2]

For lecturers, the advantage of using such material is that they can rely on quality-assured content, which allows one to integrate content from a different discipline into one's teaching without preparing educational content like textbooks or lectures for each topic. Furthermore, it is not possible to have deep expertise in all fields that are related to one's own work. OER can help solve this problem. This is especially relevant when integrating AI competencies in domain-specific course settings. Moreover, such a dynamic and open teaching setting creates a new and uncommon situation for lecturers. Their role changes from being a knowledge broker to being a learning coach. The lecturer is no longer solely responsible for explaining the content but becomes a learning companion who guides the students through their individual learning process. Consequently, studying with OERs also empowers the self-responsibility of the students.

From a didactic perspective, integrating OERs causes a new organisation of the learning process that forms a learning pyramid, illustrated in Figure 1. Lecturers, students, and the object of learning usually form the so-called didactic triangle in which the learning process is organised [5]. When digital educational material is used additionally, the triangle forms a three-sided tetrahedron as described by Prediger et al. [5]. However, we argue that the digital lecturers who are the creators of the digital educational material also influence the learning process. Thus, the learning process forms a didactic pyramid of teaching.

Lecturers in such a setting are confronted with a multitude of challenges. At the same time, integrating OERs in teaching opens up space for more self-directed learning and for learning settings that enable a highly interdisciplinary, practical acquisition of knowledge and skills. In the following, we show how the integration of OERs differs in a project-based learning scenario.

2.2 Using OERs in Project-based Learning

There are multiple ways of integrating OERs. In a classical way, they can be used for self-study before a class. Thus, students consume and study selected material as a prerequisite before their class, and the lecture is used to deepen and apply the studied material (so-called "Flipped Classroom") [6]. In this context, a lecturer needs

[2] An example for curated AI learning opportunities is the AI campus, available at *ai-campus.org*.

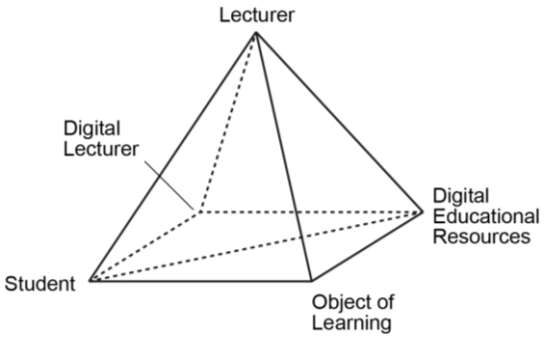

Fig. 1. Didactic pyramid of teaching that extends the didactic triangle of lecturer, student, and object of learning with an additional digital lecturer and digital learning material.

to communicate the learning goals and guiding questions clearly or curate the material for the students (see for example Fig 2-C, prep. phase).

In the project-based learning setting, the use of OERs is *on demand* throughout the project, as illustrated also in the implementations in Fig. 2. Here, students have access to a (curated) library of material and study selected material based on their individual needs. This fosters self-directed learning and allows for a more individual, practice-based learning experience in the different phases of a project. Furthermore, relying on OERs as knowledge broadcasters allows to provide a broader range of specific project topics that would be not possible to cover as an individual lecturer. At the same time, students are still accompanied by their teacher, who helps them understand the external content and answers open questions.

The use of OERs in PBL is especially useful in interdisciplinary settings like AI in engineering, where the classical domain know-how is combined with new data-driven methodologies. Furthermore, it can address heterogeneous groups of students, different levels of experience and even interdisciplinary project settings. To exemplify the use of OERs in a PBL setting, the next section discusses the implementation of *on demand* OERs in three different courses and summarises our lessons learned.

3 IMPLEMENTATION

3.1 Research Project Seminar

An implementation of the concept of a research project seminar was done in a project seminar (5 ECTS-CP) focusing on developing an algorithm that can track an arbitrary moving object over time. In the project, we incorporated collaboration and competition using teams consisting of 24 students from computer science, medical engineering, and AI. As the audience was very heterogeneous, OERs were a central theme to supplement the individual's knowledge at the beginning of the seminar (see Fig. 2-A). In the first phase, the lecturer selected a range of OERs as a prerequisite of the course.

Throughout the course, every student had the aim to implement a tracking algorithm. In this phase, students had the opportunity to access further OERs on relevant topics around tracking algorithms. However, this was not mandatory and based on their needs. The lecturer supported finding the right material for the respective student groups by providing guidance and pointing to general and more specific OERs.

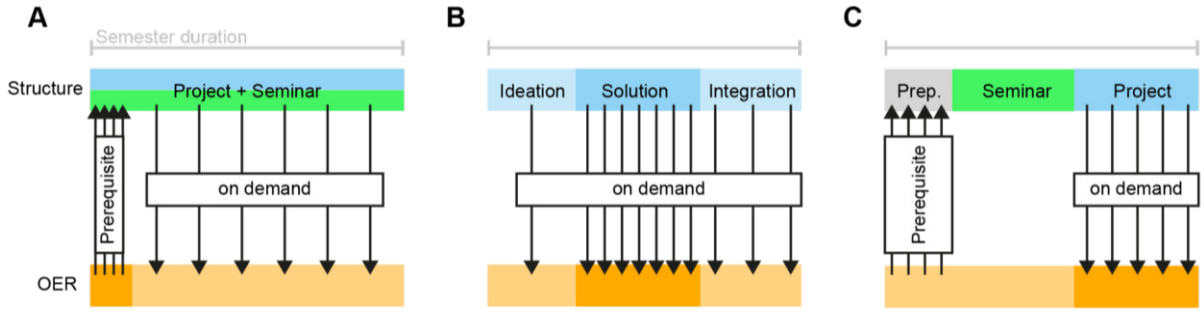

Fig. 2. Overview on discussed implementations of teaching AI competencies with OERs and projects: A) Implementation as a research project seminar, B) Implementation as product engineering project, C) Implementation as a block project seminar. Arrows indicate if students were provided with OERs as a prerequisite or used them on demand.

To succeed in the seminar, the student groups needed to collaborate within their teams to find a common team solution. At the end, each student presented a paper or created their own OER related to the project topic. The latter should foster the creation of new, specialised high-quality OERs which could be potentially used in future semesters. However, the quality of the student-created OER varies.

3.2 Product Engineering Project

The implementation was done in product engineering projects (5 ECTS-CP) for students from mechanical engineering in their 4th or 6th semester without previous knowledge of AI. Here, the concept of fully on-demand OERs was tested (refer to Fig. 2-B). The projects aimed to teach students an understanding of how smart, data-driven products work and how to include AI components in engineering products. Exemplary project topics varied from developing a machine that sorts LEGO bricks, developing an autonomous car control in a car simulator, or implementing games with AI components in online environments.

Since the overall goal in the course was teaching product development, the project started with a definition and ideation phase, where the requirements to the solution and the fulfilment criteria were specified. Next, the development followed the traditional way of product engineering by defining functions and their relations as a basis for partial solutions that shall be investigated. When using this development approach, it is not clear beforehand what part of the solution uses an AI component and how the component is integrated into the overall system. Therefore, the students accessed required material and knowledge needed to develop their solution on demand as OERs. Thus, the knowledge transfer was not provided through classical lectures with clear, defined topics but through flexible on-demand OERs.

3.3 Interdisciplinary Project Block Seminar

Another form of integration was done in the interdisciplinary seminar on the topic of AI in Neuroscience (3 ECTS-CP). The aim was to equip participants with the knowledge and ML tools to analyse electroencephalography (EEG) data. The small, heterogeneous and interdisciplinary group consisted of eleven students with backgrounds in computer science, psychology, and neuroscience as well as different semesters.

Similar to the block research project described in Fig. 2-C, the seminar had three phases: self-preparation, seminar days, and a project phase. It combined the idea of an inverse classroom concept with PBL. OERs were used in two parts. First, in a curated form as a prerequisite for the preparation of the seminar and second, on-demand as support during the implementation of the project phase. By integrating OERs in the seminar, the participants were addressed based on their background and needs. Furthermore, the seminar days could be used for group work rather than knowledge transition, focussing more on applying the knowledge.

3.4 Lessons Learned

From implementing the courses and evaluating them in open discussions with the participants, we can already derive the following lessons learned:

- Students perceived the integration of digital material as helpful, especially highlighting the flexibility of short videos and other forms of material, such as podcasts.
- Students experienced self-directed learning and autonomy as satisfying and self-affirming.
- Investing time at the beginning of the course in discussions and definitions of goals and tasks pays off in the remaining time of the course. Moreover, it also allows students to embrace the openness of the process.
- Using OERs allows lecturers to integrate AI content into the particular domain without the need of preparing their own learning content for all possible topics.
- Working on practical problems helps the students to gain a hands-on understanding of the underlying AI concepts.
- Projects help to teach AI in its relevant, domain-specific problem context and support students to understand the benefits and limitations of the technology.
- The availability of high-quality OERs for the specific project context and experience level is a limiting factor (especially in the fast-moving field of AI).

4 DISCUSSION

4.1 Changing Role of Lecturers

The integration of OERs into a course or a project causes a new situation concerning the role of the lecturers. They are no longer the only lecturer in the course, because of the digital learning content that is created and partly conducted by another digital lecturer. First, this means giving up some of the control a lecturer usually has during a course. Second, it also requires the lecturers to re-interpret their own role when it comes to dealing with external content that is neither from their own discipline nor designed in their own teaching style. Experiencing different teaching styles, different ways to present knowledge, and different levels of difficulty can be helpful for students. At the same time, it can be a challenging, new situation for the lecturers who need to become mentors, learning companions and curators rather than being the single source of knowledge. It is, therefore, important to reflect and communicate the role in the learning process.

The use of OERs and projects also bring different advantages for the lecturers. First, there is the obvious benefit of relying on curated material, which is helpful in a field

that is not part of one's own expertise. The knowledge transfer of certain topics is partly outsourced to domain experts. Second, the use of external material can save time in the course preparation and in more resource-intensive settings like project-based learning. It might even be the only way to cover the possible wealth of learning material at all. Done right, the lecturer has more time for discussing and conducting, which becomes the new key function of the lecturer.

4.2 Effect on Students

Challenges are not only imposed on the lecturer when using project-oriented approaches in class. Students also have to adapt to the new learning situation and have to leave a consumer's role in favour of a more active self-concept as learners. Suddenly being responsible for one's own learning process, for the organisation of real-world tasks, communication, and structuring problems may be challenging, especially for students in earlier semesters.

The lecturer has to bear this in mind when planning a course. It includes providing students with material or guiding questions to enable them to master processes and tasks in a self-directed way. Some students may be able to succeed here with nearly no help. Others may need more attention or help at a certain point. Thus, the lecturer has to focus more on individual learning and adaptive learning designs, when choosing material and creating tasks for the students. Tasks have to be formulated very clearly and precisely to prevent misconceptions. Clarifying the goals and possible questions right in the beginning is very important and may well take more time than in other settings. Yet afterwards, students should be able to act more or less independently without constant input from their lecturer.

5 CONCLUSION AND OUTLOOK

In this paper, we proposed to combine OERs and PBL to teach applied competencies in an engineering context focusing on the example of AI competencies in engineering. We combined the open format of a project with a curated form of on-demand open education content. Furthermore, we presented three different ways of implementing the combination in courses across levels and disciplines focusing on integrating AI into different domains. The first results and lessons learned indicate that using OERs and PBL can be a useful way to extend existing teaching formats towards more practical and applied learning with a manageable effort. This also suggests an additional benefit of sharing high-quality open educational content.

Our findings are limited to the experience from the three implementations. Thus, further work is needed to generalise the concepts and provide more evidence on the effects on students and lecturers.

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