Work-in-Progress: KICK 4.0 - AI Chatting Skills in the Engineering Laboratory

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Dr. May serves as a Professor for Technical Education and Engineering Education Research at the School of Mechanical Engineering and Safety Engineering at University of Wuppertal. His work revolves around generating both fundamental and practical knowledge that defines, informs, and enhances the education of engineers.

His primary research thrust centers around the development, implementation, practical utilization, and pedagogical value of online laboratories. These laboratories span a range of formats, including remote, virtual, and cross-reality platforms. Dr. May's scholarly pursuits extend into the sphere of online experimentation, particularly within the context of engineering and technical education. Prior to his role at the University of Wuppertal, Dr. May held the position of Assistant Professor within the Engineering Education Transformations Institute at the University of Georgia (Athens, GA, USA).

Central to Dr. May's scholarly endeavors is his commitment to formulating comprehensive educational strategies for Technical and Engineering Education. His work contributes to the establishment of an evidence-based foundation that guides the continual transformation of Technical and Engineering Education. Additionally, Dr. May is actively involved in shaping instructional concepts tailored to immerse students in international study contexts. This approach fosters intercultural collaboration, empowering students to cultivate essential competencies that transcend cultural boundaries.

Beyond his academic role, Dr. May assumes the position of President at the "International Association of Online Engineering (IAOE)," a nonprofit organization with a global mandate to advocate for the broader advancement, distribution, and practical application of Online Engineering (OE) technologies. His leadership underscores his commitment to leveraging technological innovation for societal progress. Furthermore, he serves as the Editor-in-Chief for the "International Journal of Emerging Technologies in Learning (iJET)," a role that facilitates interdisciplinary discussions among engineers, educators, and engineering education researchers. These discussions revolve around the interplay of technology, instruction, and research, fostering a holistic understanding of their synergies.

Dr. May is an active member of the national and international scientific community in Engineering Education Research. He has also organized several international conferences himself – such as the annual "International Conference on Smart Technologies & Education (STE)" – and serves as a board member for further conferences in this domain and for several Divisions within the American Society for Engineering Education.

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Introduction

Many universities lack the resources to give all students equal access to hands-on lab work. Online labs offer one way to overcome this challenge. Significant advances in AI technologies in recent years, particularly in natural language processing (NLP) applications such as ChatGPT, have created new opportunities to shape lab teaching in the context of engineering education at universities, improve the educational experience of online labs and reduce reservations about AI technologies in practical use.

The KICK 4.0 project aims to integrate NLP AI systems into laboratory teaching. The aim is to train users in the skills required to use NLP AI technologies. Students and teachers alike should be able to experience the potentials and limitations of AI technologies and thus, on the one hand, significantly develop their skills in dealing with NLP AI and, on the other hand, substantially strengthen confidence and acceptance in AI technologies. To this end, pedagogical teaching and learning scenarios for solving real-world problems will be developed as part of a laboratory course in the lecture on fluid mechanics in mechanical engineering studies. This approach aims to provide students with essential AI skills for society and the world of work in a reflective and critical way and to promote their problem-solving and creative thinking skills. This conference paper presents work carried out as part of the KICK 4.0 project. The research questions derived from this are:

RQ1) What skills are required in dealing with NLP AI?
RQ2) What are the strengths and limitations of NLP AI technology?
RQ3) How can users be supported in developing individual problem-solving skills and creative thinking?
RQ4) What do scenarios for the effective use of NLP AI technologies in university laboratory teaching look like?

Method

Design-Based Research Approach (DBR approach)
The KICK 4.0 project is part of the Fluid Mechanics module in the Mechanical Engineering program at the University of Wuppertal. This includes the laboratory practical course Computational Fluid Dynamics (CFD). In this course, students learn how to use complex software (OpenFoam) to solve fluid mechanical problems. The implementation of the project in an ongoing course and the aim of involving students and lecturers in the development process suggests the implementation on the basis of a Design-Based Research (DBR) approach.

In the context of a DBR approach, the term intervention describes targeted measures or changes within an educational context that aim to optimize learning processes, test new educational concepts or tackle existing challenges. The interventions should only be evaluated summative after advanced refinement; i.e. the development potential of the interventions should be exhausted before an approach is discarded as unsuitable [1].

The DBR approach attempts to interlink the development of innovative solutions for practical educational problems with the acquisition of scientific knowledge [2] and follows a cyclical and iterative process in which design, testing, analysis and redesign continuously build on each other. On the one hand, this increases the quality of innovations in teaching and learning research and, on the other hand, relevant findings are gained for the specific field of practice [3]. The core idea of DBR is that learning situations are not investigated in isolated laboratory environments, but in real situations [4]. The objectives pursued are always twofold: on the one hand, relevant problems from educational practice are to be solved and, on the other hand, theory-generating or theory-developing results are to be obtained [5].

Within the KICK 4.0 project, the specific problems have already been formulated (see research questions). The DBR approach can thus be divided into four phases, which are briefly described below (see Figure 1).

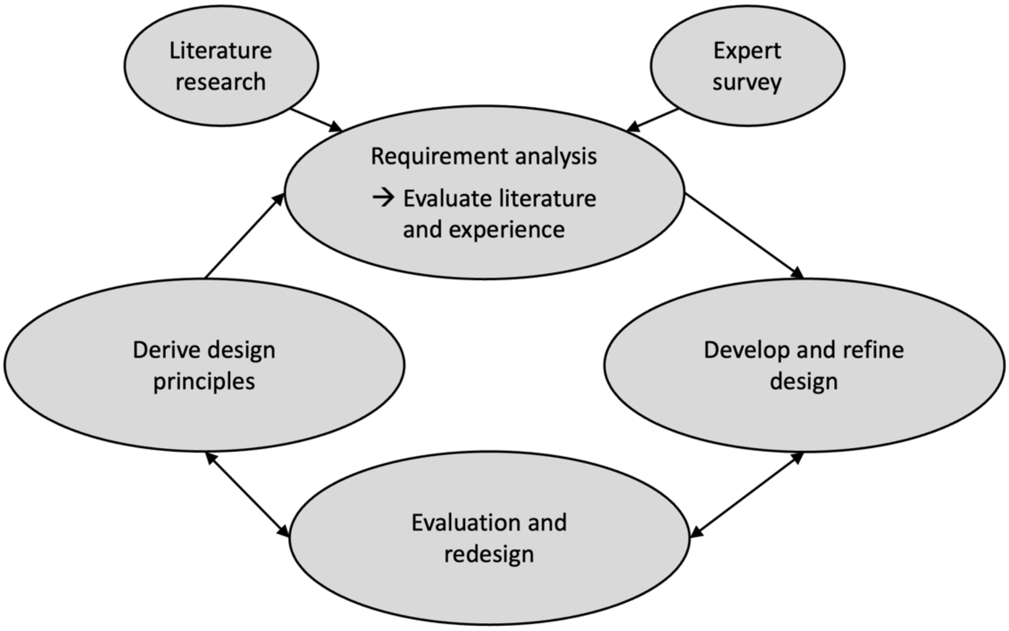

Figure 1: Adapted research and development cycle based on [1]

The first step is to carry out a requirements analysis. Here, a practice-relevant problem is analyzed in a theory-based manner, e.g. by determining the current state of research as part of a systematic literature review or by determining the status quo through an initial survey [6]. The implementation of surveys makes it clear that the DBR approach is use-oriented, as designs for the concrete solution of practical problems are developed in a theory-oriented process [4, 7, 8].

The second step consists of the theory-based development of various prototype designs, taking into account the results from step 1. In parallel, possible evaluation methods for measuring the effectiveness of the developed intervention measures are developed.

In the third step, the intervention and evaluation phase, interventions are carried out in an iterative process with the designs created, scientifically evaluated and then revised. It is often advisable to initially carry out the planned intervention with a single, small target group in a first evaluation cycle [9]. The need for revision arising from the analysis results of the implemented interventions is then implemented and examined in adapted evaluation cycles. Through this cyclical process, the designs are constantly tested, refined and evaluated with the involvement of all groups of people involved in the intervention until, in the best-case scenario, a solution to the initially formulated problem is achieved through a design.

In the fourth step, design principles are derived and formulated from the solutions developed. At the same time, the underlying theory is further developed. This illustrates that DBR not only has to be theoretically sound, but also contributes to new theories or the further development of existing theories and at the same time generates implications for practice [10].

Design-Based Research Approach in KICK 4.0

The following steps describe the application of the DBR approach in the KICK 4.0 project. The definition and specification of the problem was carried out in the conception phase of the project and summarized in the research questions formulated in the introduction.

Step 1: Requirements analysis (evaluate literature and experience)

The requirements analysis is divided into two aspects. The first part of the requirements analysis consists of a systematic literature search and document analysis on the current state of AI-based teaching in STEM subjects. For this purpose, a standardized nine-step procedure was applied, which is based on the approach of [11] and [12]. The research objective of the systematic literature review is to provide a comprehensive overview of NLP applications in laboratory-based engineering education. The research questions of the systematic literature review correspond to the overall research questions (see Introduction). In the further course of the literature research, the research questions were broken down into key components and 11 main keywords were defined. The keywords are “lecturers” and “students”, “NLP” and “AI”, “engineering education”, “potential”, “risk” and “limitations”, “feedback”, “competencies” and “laboratory”. In addition, synonyms “ChatGPT”, “gen AI”, “higher education”, “technical education”, “advantages”, “changes”, “opportunities”, “critics”, “disadvantages”, “experiences”, “digital labs” and “online labs” were used, to name but a few. Search strings were defined from the keywords and synonyms. These were used in the databases “ScienceDirect”, “Scopus” and “Web of Science”. The period from 2020 to 2024 was considered. The detailed literature research procedure and the results are dealt with in a separate article.

The second part of the requirements analysis is the survey of relevant groups of people, taking into account the results of the literature research. The surveys are conducted at the beginning and end of each semester. The relevant group of people are students of the Master's degree programs “Fluid Mechanics” and “Computer Simulation and Science” as well as lecturers at the University of Wuppertal. Due to the expected small number of students, qualitative methods of empirical educational research are used to carry out, analyze and evaluate the interventions. The Plus-Minus-Interesting method (PMI) developed by Edward de Bono offers people the opportunity to deal with a specific problem, weigh up the pros and cons and make a weighting. This method helps to assess consequences and find alternatives [13].

The students' task is to use the PMI method to work out the potential advantages, disadvantages and interesting aspects of using NLP AI technologies such as ChatGPT in the CFD course.

- Plus (+): Identify the positive aspects (advantages, benefits) of using ChatGPT in this course
- Minus (-): Identify the negative aspects (challenges, risks) associated with ChatGPT in this course
- Interesting (I): Identify neutral or interesting aspects (things that are neither strictly positive nor negative but should be explored further).

The second part of the survey consists of a focus group discussion on two specific questions.

- How can ChatGPT support you as a student in the CFD course?

- In your opinion, are there any use cases in the context of the CFD course where the use of ChatGPT is particularly suitable?

Similar to prototype development, the methods used to evaluate the effectiveness of the prototypes employed are subject to an iterative process and are developed further in each development loop.

In the first iteration loop, the students have the task of using ChatGPT as an NLP AI in the course without being influenced by the teachers. The aim is to find out what expectations the groups associate with NLP AI technology and what challenges and potential they see when using it in laboratory teaching. In the following iteration loops, the evaluation methods are adapted to the development of the prototypes.

Step 2: Development and refinement of the prototype
Based on the results of the requirements analysis, a prototype is developed for the use of a real scenario for the effective use of NLP AI technology. In addition, evaluation criteria are derived from the results of the requirements analysis in order to assess the effectiveness and practicability of the prototype used. Further interviews with the relevant groups of people are aimed at improving the evaluation criteria determined, validating the effectiveness of the prototype used and, if necessary, developing possible improvements.

Step 3: Evaluate intervention and redesign
This loop is repeated in subsequent semesters, the prototype is redesigned and the result is further concretized.

Step 4: Derive design principles
Based on the results, design principles are developed that demonstrate the possible applications of NLP AI technologies in laboratory-based engineering education in STEM subjects. This will ensure that the results are transferable to other engineering disciplines and contribute to the dissemination of the concept. The results of the project will be published and made available to the community for further research.

Results

At the time of writing, the KICK 4.0 project is in the requirements analysis phase, consisting of a systematic literature review and a survey of relevant groups of people.

Preliminary results of the literature research
The overarching aim of the systematic literature review is to provide a comprehensive overview of NLP applications in laboratory-based engineering education. A majority of the results from the literature review suggest that the predominant research seems to focus on model development and improvements of language-based tasks. Context-specific applications such as pedagogical aspects in engineering education or embedding in laboratory teaching are poorly represented [14]. Furthermore, the data suggest that research on AI/NLP applications in engineering contexts, especially in relation to education and laboratory work, is underrepresented compared to studies in non-engineering disciplines. Despite the growing interest in AI-supported education, current studies rarely focus on engineering laboratories, especially on the role of NLP-based real-time feedback mechanisms [14].

In this context, one of the key ways to support the development of individual problem-solving skills and creative thinking is through timely and adaptive feedback, as seen with tools like ChatGPT. These systems can adjust to a learner’s current understanding and offer real-time responses that help guide thinking rather than just delivering answers. By prompting students to explore alternatives, reconsider their approaches, and clarify their reasoning, such feedback encourages active engagement with the content. Early findings suggest that immediate support of this kind not only boosts motivation but also helps reduce uncertainty and frustration, creating a learning environment where students feel more confident and capable of tackling complex problems—both independently and creatively.

Preliminary results of the "survey of relevant groups of people"
At the time of writing, a survey of students was conducted as part of the requirements analysis. The students were attending the CFD (Computational Fluid Dynamics) course and were interviewed at the beginning of the semester. A total of three people took part in the survey. The students' task was first to use the PMI method to identify the potential advantages, disadvantages and interesting aspects of using ChatGPT in the context of the CFD course. This was followed by a focus group discussion on two specific questions (see chapter 2). The references to the literature refer to the results of the literature research with equivalent results.

Preliminary results of the survey show that students find the use of tools such as ChatGPT helpful. They appreciate the accessibility and availability of the tool (see also [15]). It was also confirmed that students regularly use AI technologies such as ChatGPT. They use it to get a quick overview of a topic they are unfamiliar with and to find a starting point for further action. It should be emphasized that they perceived the possibility of being able to address questions to the AI at any time as a driver for their own learning motivation and used ChatGPT to create a "learning note" and thus actively support the individual learning process (see also [16]).

The results of the survey also show that the students are fully aware that ChatGPT answers can be incorrect and that the tool cannot be used without reflection. They also know that the quality of the answers depends largely on the question. One student saw the danger that regular use of ChatGPT could impair their own learning success quote "If I don't make an effort, I won't remember it."

In addition, students expressed a desire for supportive and motivating feedback that would encourage them to engage more intensively with the learning content (see also [15]). They would like advice on finding solutions instead of direct answers and feedback on areas in which they have difficulties (see also [13]).

Conclusion and Further Steps

Conclusion
The KICK 4.0 project investigates the possible applications of NLP-AI technologies to increase learning success in the context of laboratory-based engineering education. The results of the literature review show that the focus of research is predominantly on model development and language-based tasks, while pedagogical and laboratory-specific applications are hardly considered. In addition, research on AI/NLP in engineering contexts is underrepresented compared to non-technical disciplines. The results of the surveys conducted within the project so far do not provide any new findings, but are in line with the results of the literature review.

Further teps
First, the literature research is completed, focusing on the analysis, clustering and evaluation of relevant sources. These are systematically evaluated with regard to the identified focus topics of "feedback", "potentials and limitations" and "competence requirements". At the

same time, the results of the requirements analysis will be evaluated and extended to other relevant groups of people (e.g. teachers).

Furthermore, it is planned to look at the research questions in isolation and to develop specific measures and evaluation methods for the respective questions, which will make the use of NLP AI in university teaching motivating and conducive to learning. In order to ensure the validity and reliability of the results obtained, an evaluation framework will be developed. This is intended to systematically validate the results and identify optimization potential.

These measures will be integrated into the prototype of an "AI assistant" and evaluated in future courses. The use of other NLP AI tools, such as LlaMA, will also be examined in collaboration with other projects. Finally, the concept is to be disseminated in the STEM field in order to promote its applicability in scientific and technical fields of education and contribute to improving teaching in these disciplines.

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