Online-Journals.org

iJEP International Journal of Engineering Pedagogy

iJEP | eISSN: 2192-4880 | Vol. 14 No. 6 (2024) | OPEN ACCESS

https://doi.org/10.3991/ijep.v14i6.47519

PAPER

Project- and Research-Based Teaching in Civil Engineering

Niels Bartels[1](✉), **Katrin Stolz**[2]

[1]University of Applied Sciences Cologne, Cologne, Germany

[2]Technical University Dortmund, Dortmund, Germany

niels.bartels@th-koeln.de

ABSTRACT

Research-based practical applications are becoming increasingly important in providing valuable solutions to the challenges facing the construction industry. In this paper, we present a teaching concept that was implemented and evaluated in four courses, addressing the development of future-proof academic skills, particularly scientific working skills, in the field of civil engineering. The first evaluation results from a survey among the students who participated in the four courses are presented on the extent to which project-based and research-based learning promote domain competences, planning, and study skills. The results indicate that, especially in master's degree courses, future skills are improved by paper-based learning. Additionally, student motivation increases due to the boost in creativity and group work facilitated by the teaching concept. On the other hand, the results suggest that guidelines are necessary to implement paper-based learning, especially in bachelor's degree courses. Furthermore, it is crucial that future-proof academic skills are relevant for success in the practical working context.

KEYWORDS

future-proof academic skills, scientific working skills, study-based learning, student motivation, civil engineering

1 INTRODUCTION

Innovations in university teaching are necessary to prepare university graduates for the future world of work, which is changing in the face of complex social challenges and digital transformation. "21st century" skills are required [1, 2], such as high analytical, social, and digital skills [3]. The German Science and Humanities Council calls for "future-proof academic skills profiles" in its recommendations for the future-proof design of studies and teaching [4]. However, teaching in civil engineering is primarily characterized by the development of disciplinary knowledge and technical skills [5–7].

Bartels, N., Stolz, K. (2024). Project- and Research-Based Teaching in Civil Engineering. *International Journal of Engineering Pedagogy (iJEP)*, 14(6), pp. 23–36. https://doi.org/10.3991/ijep.v14i6.47519

Article submitted 2023-12-22. Revision uploaded 2024-03-25. Final acceptance 2024-04-01.

In this article, we present a teaching concept that focuses on developing future-proof academic skills, especially scientific skills (such as competencies for change management, innovation, critical thinking, and judgment), in the field of civil engineering. We also provide initial evaluation results addressing the question: To what extent does project- and study-based learning enhance domain competencies and study skills?

1.1 Development of research and teaching in civil engineering

Civil engineering is evolving through digitalization and the implementation of new project management techniques and innovative building approaches. It encompasses various specialized fields that demand diverse skills. For instance, structural engineering necessitates expertise in calculation methods and standardizations, while construction operations primarily require methodological skills for overseeing teams at construction sites, conflict resolution, and effective communication [6, 7]. Although specific skills are emphasized based on the field of study, it is essential to equip students with skills from various domains. Moreover, methodological skills such as communication, conflict resolution, scientific study methods, and teamwork are vital for professional success [8].

These methodological skills are becoming even more relevant due to current trends in the construction and real estate industries. There are two trends that are particularly important for the first author's teaching and for which students need to be trained.

1. Development and application of new project management methods, such as lean construction or building information modeling (BIM): In construction projects, the various specialist disciplines, such as structural engineering, technical building services, architecture, facility management, and geotechnics, have to work together. New project management methods such as lean construction or integrated project delivery (IPD), as well as digital methods such as BIM or smart buildings, are leading to changes in communication between the specialist disciplines. Lean construction, for example, is a method that organizes the project with the respective planning and construction processes as work steps to achieve an optimal flow of processes, improve communication between those involved, and generate maximum customer benefit through a smooth planning and construction process [9, 10]. BIM is a methodology that uses digital building models and open data exchange formats to connect disciplines, enabling transparent and lifecycle-oriented information exchange. [8, 9]. BIM is seen as one of the technologies that will have a major impact on the engineering profession [11].
2. A life-cycle-oriented view of the building is facilitated by the data exchange format, linking individual specialist disciplines together. This enables a transparent exchange of information throughout the life cycle [12, 13].

In addition to the use of new methods, there is an emphasis on considering the entire lifecycle of buildings. This includes not only the design and construction of buildings to save costs and energy but also the evaluation of costs and energy consumption over the entire lifecycle. The focus is on life cycle assessment (LCA) and life cycle costing (LCC). LCA aims to assess the environmental impact of a product or process over its entire life cycle, while LCC determines the cost development throughout the entire life cycle [12]. These influences are illustrated in Figure 1.

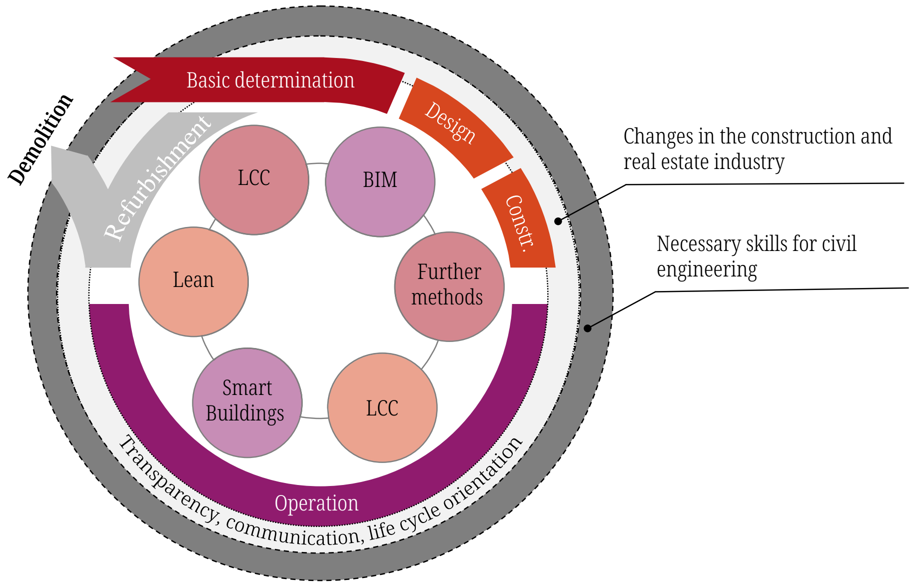

Fig. 1. Influences on civil engineering

The introduction of these new methods in professional practice necessitates the adoption of new teaching and learning approaches in civil engineering education. Consequently, new module content that aligns with these requirements is being incorporated into the curricula of civil engineering and related degree programs. Alongside the technical content covering lean construction, BIM, LCA, or LCC, there is also a need to cultivate methodological skills [13, 14].

In addition to analytical, social, and digital skills, a study-based approach is also very important in civil engineering, given the new types of problems that will arise in highly emergent practical contexts in the future (see also [4]). Research-based learning in civil engineering no longer just means "testing, measuring, and designing building materials, products, structures, and processes in practical or real projects using the appropriate methods" [14], but also developing new approaches and methods from practice. Research and development are closely linked in civil engineering [15], and research skills are therefore an integral part of the professional competencies of civil engineers.

1.2 Particularities of teaching civil engineering and future requirements

Thus, applied study is becoming more important in engineering education due to changes in professional practice. However, teaching and research in civil engineering have long been practice-oriented. This implies that study standards in teaching are not as high as in other subjects (e.g., economics or social sciences). However, the field of civil engineering is currently experiencing highly dynamic developments due to digital transformation, requirements for ecological sustainability, the need for cost-effective construction due to high interest rates, or skills shortages [16]. In this highly dynamic context, it becomes more important to develop solutions in a highly emergent practical context. Specifically, this means that study-based practical application becomes more important to find valuable solutions for the challenges of the construction industry. In a position paper in 2015, the German Federal Chamber of Engineers defined the required study skills for bachelor's degree programs in engineering as follows: Graduates should have the ability to conduct guided practical research and to compile and interpret empirical data using qualitative and quantitative methods [17].

In particular, the integration of practice, study, and development is a common practice in civil engineering. For student education, universities must incorporate study and development competencies. Teaching needs to be developed at the intersection of study and employability. Therefore, applied sciences are well-suited for this purpose. Students should be encouraged to view study and development as an essential component of their professional skills. These competencies include:

- Engaging in studies, such as literature reviews and online studies, and discussing the results within the realm of applied sciences.
- Developing a study and development design.
- communicate and present their knowledge by writing a paper and making presentations of the results.

This necessitates integrating the development of domain-specific skills with study and development skills in the civil engineering curriculum at universities to enhance sustainable employability through academic proficiency.

Against this background, a teaching concept was evaluated in the modules "Digital Technologies in the Life Cycle" and "Lifecycle Engineering" at the Cologne University of Applied Sciences (TH Köln). The concept aims to enhance methodological skills such as scientific work and teamwork.

In Part 2 of this paper, we will outline the teaching concept on which the module is based and then present the initial results in Part 3.

2 TEACHING CONCEPT

The development of study- and work-related domain skills is typically considered separately in civil engineering education. In the authors' experience, study skills are primarily taught through exercises on scientific work. In the modules outlined in this paper, inquiry-based teaching was employed as the fundamental teaching method to combine the acquisition of domain and study skills. Inquiry-based teaching involves a variety of teaching techniques that emphasize the creation of questions and the process of developing, testing, and evaluating explanations [18].

In the Bachelor module "Digital Design and Construction" and the Master modules "Life-cycle Engineering" and "Digital Technologies in the Buildings Lifecycle," study-based learning was utilized as a teaching concept. In contrast, project-based learning was employed in the Bachelor module "Building Information Modeling." These two learning approaches share close similarities in terms of the underlying didactic principles and the didactic-methodological approach [19]. However, study-based learning focuses on the key objective of science or study, while project-based learning aims to connect with professional practice.

In study-based learning, students learn central concepts, theories, and methods of the domain by independently formulating study questions, searching for literature, developing and implementing study designs, and presenting the results in a suitable scientific format such as a paper or a presentation. Thus, the students actively engage in a complete study process [20]. According to Huber [18], in study-based learning, students can "co-design, experience, and reflect on the process of a study project in its major phases—from the development of questions and hypotheses to the selection and application of methods to the review and presentation of results—through autonomous work or active participation in a comprehensive project." (p. 11). Therefore, study-based learning is one of the teaching approaches that emphasizes the social construction of knowledge and active student engagement. The extent to which study-based learning has found its place in engineering teaching is controversial. [21]. Places for research-based learning in engineering studies include seminars and laboratory exercises [19]. There is an extensive body of research and development on research-based learning in laboratories [20]. However, there are hardly any publications on research-based learning in the engineering sciences outside of engineering laboratories.

According to [22], the project-based learning approach is favored in engineering. In *project-based learning*, projects are at the center of student learning activities. Students learn central concepts, theories, and methods of the domain by working on work-related practical projects. The starting point for student project work can be a problem to be solved, a phenomenon to be investigated, or a model to be developed [18].

The first author, as the person in charge, has defined three different work assignments for the modules. These were adapted to the previous modules and forms of learning in the curriculum and supplemented with specific skills for students that had not yet been taught in previous modules (e.g., scientific work, design thinking, study).

- **Master modules "Lifecycle Engineering" and "Digital Technologies in the Buildings Lifecycle"** (n = 37 students, master paper = M_{Pa}): The task of the master students was to write a paper on a given topic, in this case "Cost modelling over the building life cycle using digital technologies." The paper was written during the semester and comprised 15 pages, including literature, in a predefined template. At the end of the semester, a presentation of the results was held in addition to the submission.
- **Bachelor module "Digital Construction and Design"** (n = 186 students, Bachelor Paper = B_{Pa}): The task in this bachelor's module was to produce a paper of between 3,500 and 4,500 characters on the topic of "Metaverse in the construction industry." The results were presented as part of a World Café. Here, student groups presented their findings to other groups in short pitches (approximately. five minutes per group). Each group consisted of 10 students per session, allowing each student to listen to and discuss with nine other groups.
- **Bachelor module "Building Information Modeling"** (n = 64 students, Bachelor Project = B_{Pr}): The task here was the project-based creation, design, and calculation of a building using the BIM methodology in various software products. The final model with the calculations as files was submitted.

The modules are structured into a lecture and an exercise where the study project work is situated. The students collaborate in teams on the study projects. Throughout the semester, five phases of group work occur. Following a **kick-off** (phase 1) where the evaluation criteria of a good paper are discussed, a **brainstorming** session is held (phase 2). In this phase, students utilize mind maps and the 6-3-5 method (six people generate three ideas each in five rounds). In phase 3, students engage in **group work** on their papers. Tutorials on academic study and work are conducted during this phase. Additionally, students regularly present their ideas to the class.

Phase 4 involves a **prereview**, which is only carried out in two of the four courses. The final phase, phase 5, includes the **final presentation, examination,** and feedback session. These phases are illustrated in Figure 2.

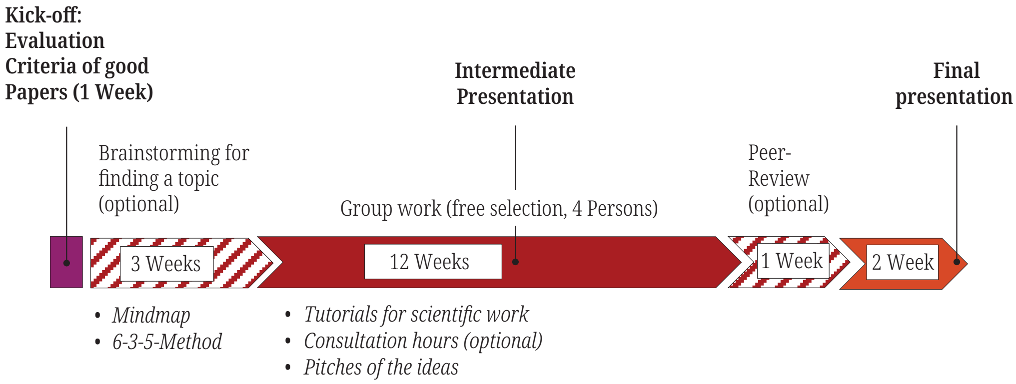

Fig. 2. Phases during the semester

The central question addressed in this article is: To what extent do study- and project-based learning enhance domain and study skills? According to Bloom's taxonomy of learning objectives, it is reasonable to assume that fostering higher-order competencies such as analysis, development, and evaluation also encompasses fundamental vocational skills. Bloom delineates six levels of proficiency, ranging from knowledge to evaluation, with evaluation representing the pinnacle of learning objectives [23]. Given the swift transformations in the AECO industry, individuals, including students and professionals, require the utmost levels of learning objectives, which can be facilitated through collaborative group work and paper-based learning.

3 METHODOLOGY

Against the backdrop of changes in the construction industry, the study question focused on the extent to which study- and practice-related domain skills can be developed in one module. The focus was on integrating the two aspects within the framework of lectures and exercises. Additionally, we were interested in the impact of the selected teaching strategies on study motivation and factors contributing to effective collaboration in student groups, as these are key elements of the chosen teaching approach.

Four courses, which the main author taught over two semesters, were the subject of the teaching research project. In order to answer the question of this teaching research project, a quantitative survey was conducted at the end of the semester among the participating students. The quantitative survey was chosen as a method because it can support the hypotheses, enables direct assessment questions, and allows the students to give honest answers due to their anonymity. In total, 287 students participated in the courses: 250 in bachelor modules and 37 in master modules. The bachelor students were split into a paper-based module and a project-based module, while all master students wrote a paper in their courses. 67 of the students answered the survey at the end of the semester. It took, on average, 14 minutes to answer the questions. The survey was conducted anonymously online and included all 15 questions in four sub-questions. In our study, we chose a 5-point Likert scale as the response format, as it was shown that respondents perceive this as almost equidistant [24].

4 RESULTS

In this section of the paper, we present the results of four sub-questions aimed at evaluating the impact of inquiry-based learning.

– Factors for successful group work (Section 4.1)
– Influence of paper-based project work on remembering lecture content (Section 4.2)
– Influence of paper-based project work on soft skills (Section 4.3)
– Influence of paper-based and project-based group work on study motivation (Section 4.4)

These results are based on the survey that was conducted among the students who participated in the courses.

4.1 Factors for successful research project work

The first category addressed the essential factors for successful project work. The results, depicted in Figure 3, indicate a strong consensus among various module methods. Specifically, the figure illustrates that clear requirements regarding scope, form, and structure are crucial for project success ($M_{MPa} = 4.3$, $M_{BPa} = 4.13$, $M_{BPr} = 3.9$). It is noteworthy that only 3% of students consider this aspect unimportant, especially in concurring essays. Moreover, the importance of having sufficient time for project work during lectures and tutorials is emphasized, as students stress the need for ample time ($M_{MPa} = 4.4$, $M_{BPa} = 4.1$, $M_{BPr} = 4.4$). The quantitative survey highlights that the support provided by lecturers during lectures and exercises is a key success factor for effective project work.

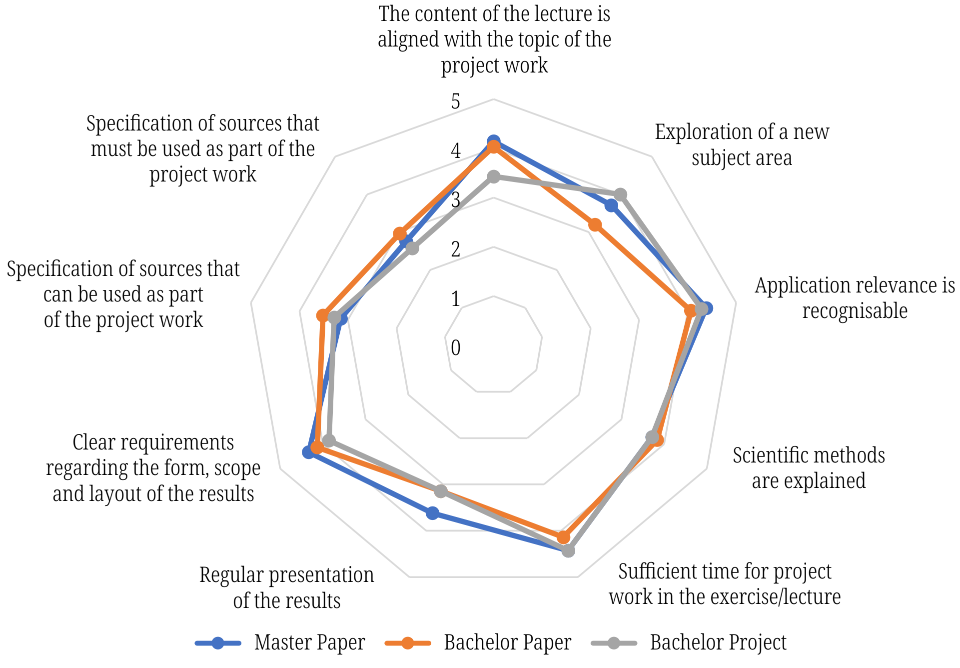

Fig. 3. Answers to the question: How relevant do you think the following factors are for the project work (n = 67)

However, it is also clear that the students want freedom, as there should be no stipulation of sources that can be used ($M_{MPa} = 3.1$, $M_{BPa} = 3.5$, $M_{BPr} = 3.2$) or have to be used ($M_{MPa} = 2.7$, $M_{BPa} = 2.9$, $M_{BPr} = 2.5$).

4.2 Influence of paper-based project work on remembering lecture content

At the end of the semester, the students were asked how the project-based work improved their understanding of the scientific content as well as how the research-based learning project increased their preparation for future jobs. The results are shown in Figure 4. It can be seen that soft skills, in particular, have been improved. The learning of methods for scientific work is enhanced by engaging in project-based work ($M_{MPa} = 4.3$, $M_{BPa} = 3.7$, $M_{BPr} = 3.4$). However, there is a distinction between bachelor and master courses, with the group involved in the project having the lowest mean value. Additionally, the development and exploration of ideas ($M_{MPa} = 2.7$, $M_{BPa} = 2.9$, $M_{BPr} = 2.5$) and the understanding of scientific work ($M_{MPa} = 2.7$, $M_{BPa} = 2.9$, $M_{BPr} = 2.5$) were increased through study-based learning.

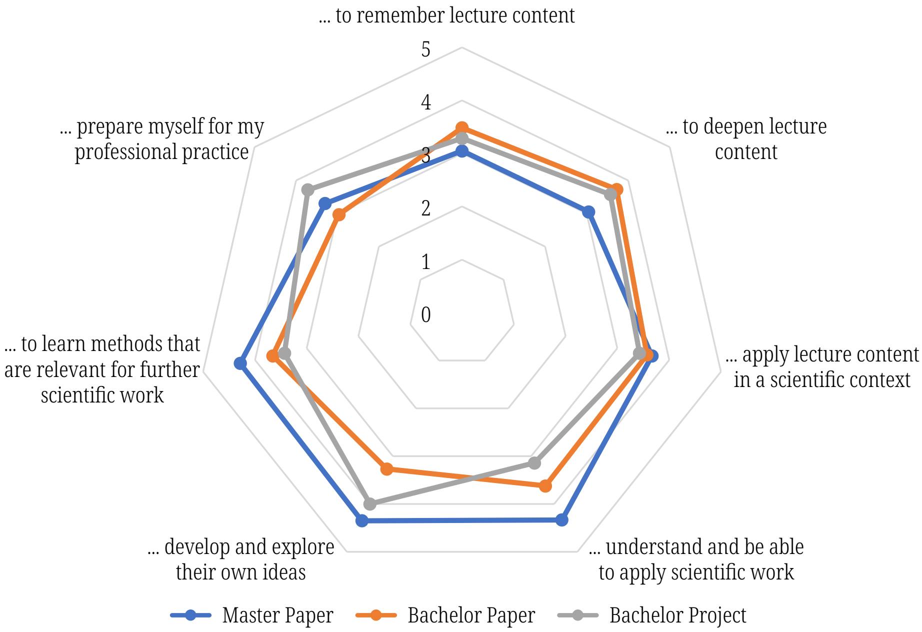

Fig. 4. Answers to the question: The project work helps me (n = 67)

On the other hand, it can be seen that the content of the lectures could not be remembered completely when compared to the aforementioned results ($M_{MPa} = 3.0$, $M_{BPa} = 3.5$, $M_{BPr} = 3.3$). The discussion with the students revealed that the content of the other group works, the scientific content, and the content of their own group work were remembered. Furthermore, the motivation to delve into lecture content was not high. Particularly in the master's course ($M_{MPa} = 3.0$), the motivation to deepen the lecture content was even lower than in the bachelor courses ($M_{BPa} = 3.8$, $M_{BPr} = 3.6$). This might result from the fact that a test with lecture content was administered in the bachelor courses.

These results were supported by further answers from the students. The students were asked if the project helped them recall important terms and subjects from the courses. While the groups that wrote papers do not fully support that statement

(M_{MPa} = 3.1, M_{BPa} = 3.2), the group that worked on a BIM project supports the statement more (M_{BPr} = 3.9). A similar result can be seen in the statement that the project makes it easier to have an overview of the course topic (M_{MPa} = 3.2, M_{BPa} = 3.3, M_{BPr} = 3.9). On the other hand, paper writing supported the assessment of the quality of specialist articles on the topics, especially in the master's course (M_{MPa} = 4.2, M_{BPa} = 3.9, M_{BPr} = 3.1). The results are shown in Figure 5.

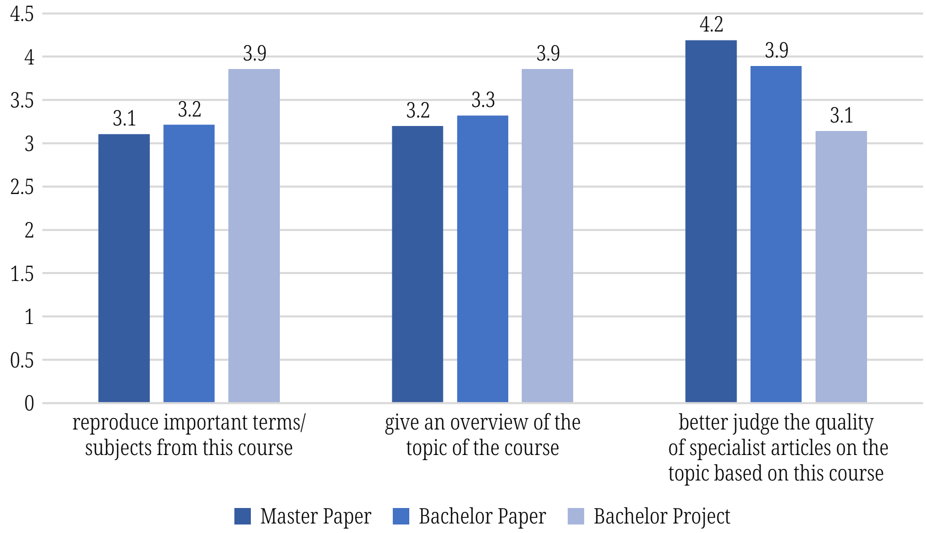

Fig. 5. Answers to the question: How much do you agree with the following statements? The project makes it easier for me to (n = 67)

The aforementioned results show that paper-based project work does not fully support the understanding of the lecture content, while project-based work on the topic helps students better understand and deepen the lecture topics. On the other hand, these initial results indicate that the development of methods has been optimized.

4.3 Influence of paper-based project work on soft skills

While the lecture content may not be fully retained and reinforced through paper-based project work, the soft and future skills of the students can be enhanced. This impact is particularly noticeable during the master's courses.

- Organization: The students in the master's course and the project-based bachelor's course have stated that they are able to organize their work more effectively because of the project work (M_{MPa} = 3.6, M_{BPr} = 3.7). In contrast, the mean value for the paper-based bachelor course is lower (M_{BPa} = 3.2).
- Presentations: Especially the paper-based master's courses indicate that the course enables students to deliver better presentations (M_{MPa} = 3.6) and exhibit more variation in their presentations (M_{MPa} = 3.5). This is attributed to the multiple presentations throughout the semester. The mean values for bachelor courses are lower than those for master's courses in terms of delivering better presentations (M_{BPa} = 3.0, M_{BPr} = 3.0) and varying their presentations (M_{BPa} = 2.7, M_{BPr} = 2.5).
- Wording and phrasing: It can be stated that the paper-based group work enhances wording and phrasing better than other project work. However, there are clear

differences between the paper-based master's course and the bachelor's course. While the master's students reported that the project helped them formulate contributions more comprehensibly (M_{MPa} = 3.5) and improved their ability to articulate their thoughts effectively (M_{MPa} = 3.4), the bachelor's students do not fully agree with these statements (M_{BPa} = 2.8, M_{BPr} = 2.7, and M_{BPa} = 2.9, M_{BPr} = 3.0, respectively).

The results are shown in Figure 6. Besides the aforementioned conspicuous features, the results indicate a difference between master's and bachelor's courses. The paper-based work notably enhanced soft skills in the master's courses.

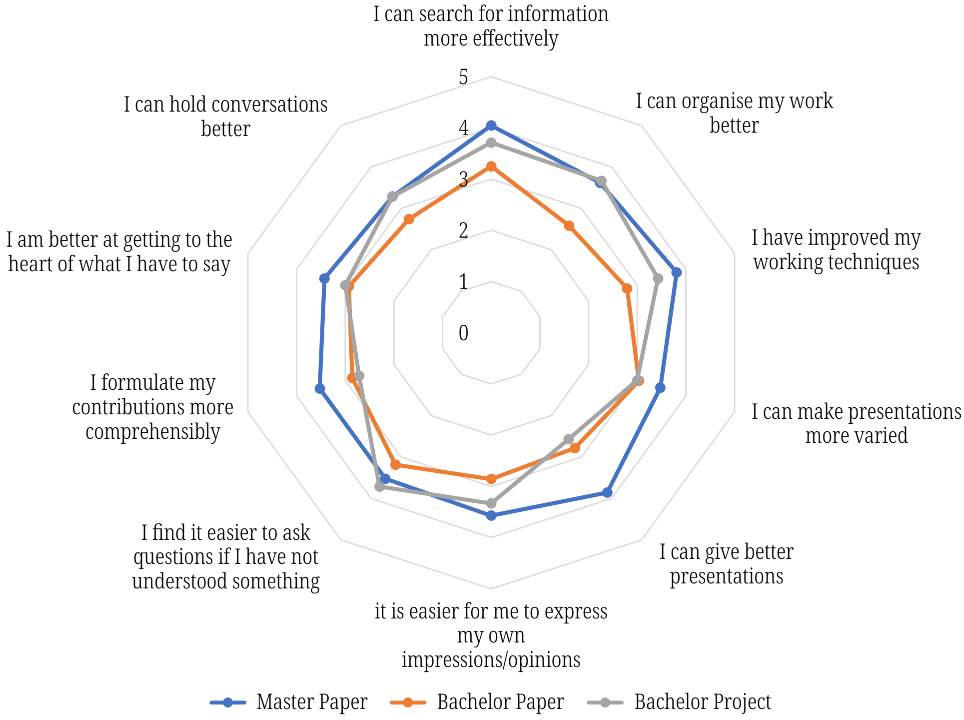

Fig. 6. Answers to the question: How much do you agree with the following statements? Thanks to the project (n = 67)

4.4 Influence of paper-based and project-based group work on study motivation

Finally, the effects of paper-based and project-based group work on student motivation were analyzed. While the results for the statements on participation in the respective groups in the different forms of group work are similar, there are clear differences in the effect on motivation for further study. These results are illustrated in Figure 7.

Especially in the master's courses, the paper-based group work led to inspiration (M_{MPa} = 4.1) and encouraged the students to continue their studies (M_{MPa} = 4.2). In the bachelor's courses, there are different results. The group work on the project motivated (M_{BPa} = 2.8, M_{BPr} = 3.3) and inspired (M_{BPa} = 2.7, M_{BPr} = 3.5) the students more than the paper-based group work.

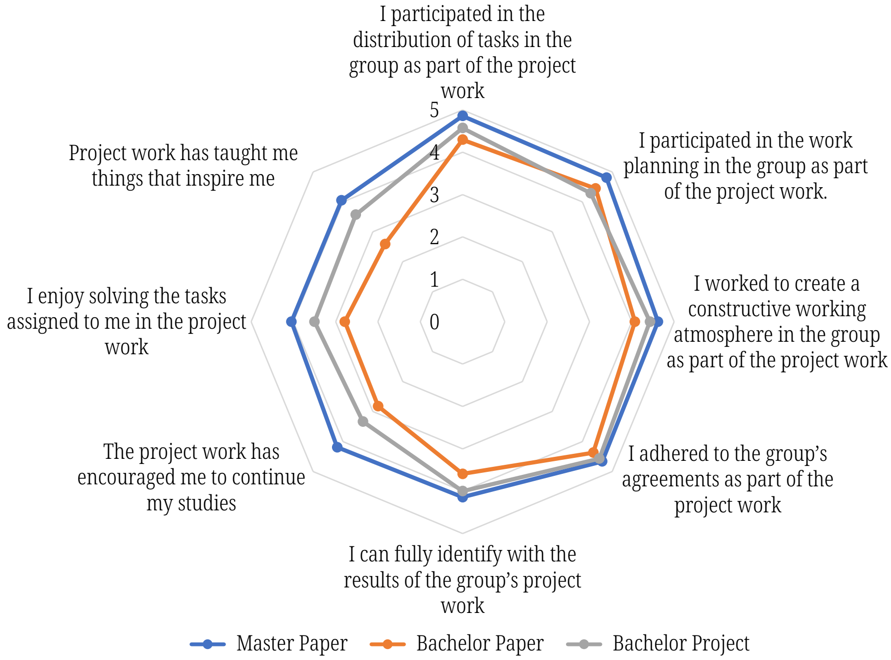

Fig. 7. Answers to the question: How much do you agree with the following statements? (n = 67)

The discussions with the students revealed that this is primarily due to a certain overload in the implementation of the paper-based project. Since no scientific work had been done in the curriculum before, there was a skeptical expectation regarding scientific work.

5 DISCUSSION

The skeptical attitude of students towards study-based learning is also evident in our survey results. Civil engineering students question the extent to which they require research skills for their work outside of university in civil engineering practice. It is essential to incorporate this question at the beginning of the module to showcase its importance. It may be beneficial to invite professionals and collaborate with them to illustrate what study activities in non-university practice entail.

In addition, a decision must be made as to whether research-based learning should already be applied to the bachelor's degree or whether project-based work should form the core of the module. The results show that research-based learning contributes to the acquisition of subject-specific skills, particularly in the Master's degree. This is due to the fact that an intensive examination of the topic takes place on the basis of professional and content-related experience. Nevertheless, it makes sense to dovetail the subject matter here. On the other hand, many more guidelines must be set for students; the basics of standards and guidelines must be taught and learned; and basic knowledge in general must be built up. This applies both to transdisciplinary group work and to subject-specific content. Therefore, the focus of the work in the bachelor's modules should be more on teamwork and dealing with people, which is also made possible by study-based learning but also by project-based work.

In bachelor's degree programs, there is a lack of motivation among students to exceed the traditional level of performance. This is partly because study-based learning is a relatively new form of education. Therefore, it is crucial, especially in the bachelor's program, to clearly outline the objectives and significance at the beginning and to emphasize the development of future skills. Furthermore, establishing a strong connection between paper-based work and lectures is essential, particularly in the bachelor's degree program, which can be facilitated through methods such as the inverted classroom. Additionally, many bachelor's students do not perceive paper-based assignments as relevant to their future careers, as they tend to think in terms of conventional job roles (e.g., structural engineering or geotechnical engineering). It is imperative to highlight the importance of acquiring additional skills and to introduce them at the outset. Lastly, motivation for this new learning approach can be enhanced by progressively encouraging academic work throughout the entire curriculum. Crafting more targeted questions that align closely with students' interests can further boost motivation.

The results of the master's degree courses indicate that students faced a specific time issue. This was attributed to the prolonged brainstorming phase caused by the broad topic. It is recommended to expedite topic definitions as much as possible by initiating brainstorming with focused (one-point) questions at the outset. This issue can be addressed by promptly assigning responsibilities and topics post-brainstorming. Alternatively, merging one with another course from the subsequent semester could provide extra time to delve into the study question. Furthermore, master's students noted a high volume of project papers being completed in the winter semester, necessitating coordination with instructors to encourage student engagement in the papers.

While the aforementioned aspects primarily pertain to the curriculum at TH Köln, the following aspects can serve as general guidelines for implementation:

1. A kick-off with explanations for academic writing is necessary. In particular, the requirements and goals of paper-based learning must be made clear. Students should learn to think independently and critically, as well as to develop innovative and novel concepts.
2. It is recommended that paper-based learning be integrated into the entire curriculum and gradually expanded throughout the respective semesters. Striking a balance between traditional examination-based learning and paper-based learning is essential to sustaining student motivation.
3. Structures and ways of thinking must be created to facilitate paper-based learning. This includes, notably, establishing a standardized assessment framework for students' work.

If the concept of paper-based learning is introduced at various universities, it can facilitate cross-university initiatives such as collaborative meetings, student workshops, and transdisciplinary learning.

6 CONCLUSION AND FUTURE RESEARCH

The results show that study- and paper-based learning can lead to an improvement in learning outcomes and an increase in soft skills. As indicated by the results, certain prerequisites for the work must be taken into account. This is especially relevant for bachelor's courses, where the fundamental basics of scientific work are still lacking.

The results will now be used to further develop the modules based on this information and to align paper-based work with the lecture content. Results will be collected continuously to assess the optimizations' impact on students and establish optimal learning conditions.

Further study is needed on the intensity and structure of paper-based learning in education. Specifically, more study is required to understand the correlation between lecture content and the time spent on paper writing to determine the ideal balance between imparting specialized knowledge and soft skills. Consequently, additional modules in civil engineering and related disciplines should be analyzed to address this issue.

In addition, further study is needed to investigate how the use of paper-based learning impacts the digital and sustainable transformation of civil engineering and young academics. A comprehensive, long-term study should involve students, graduates, and employers to assess whether paper-based learning can enhance digital and sustainable transformation.

7 REFERENCES

[1] European Commission, Ed., "Commission Communication on a European strategy for universities," *Strasbourg*, p. 17, 2022. https://education.ec.europa.eu/document/commission-communication-on-a-european-strategy-for-universities

[2] OECD, Ed., "The future of education and skills: Education 2030," *OECD* Paris, 2018. https://repository.canterbury.ac.uk/download/96f6c3f39ae6dcffa26e72cefe47684172d-a0c93db0a63d78668406e4f478ae8/3102592/E2030%20Position%20Paper%20%2805.04.2018%29.pdf

[3] D. Orr *et al.*, "Correction to: Higher education landscape 2030," in *Higher Education Landscape 2030, SpringerBriefs in Education*, Springer, Cham, pp. C1, 2020. https://doi.org/10.1007/978-3-030-44897-4_5

[4] German Science and Humanities Council, "Empfehlungen für eine zukunftsfähige Ausgestaltung von Studium und Lehre," 2022.

[5] T. T. A. Ngo, "Perception of engineering students on social constructivist learning approach in classroom," *International Journal of Engineering Pedagogy*, vol. 14, no. 1, pp. 20–38, 2024. https://doi.org/10.3991/ijep.v14i1.43101

[6] N. Schwab, "Konfliktkompetenz im Bauprojektmanagement," *Konfliktrisiken Vermeiden – Konfliktpotenziale Nutzen*. Wiesbaden: Springer Vieweg. Springer Fachmedien Wiesbaden GmbH, 2020. https://doi.org/10.1007/978-3-658-27089-6

[7] K. Zilch, C. J. Diederichs, R. Katzenbach, and K. J. Beckmann, "Konstruktiver Ingenieurbau und Hochbau," *Berlin*, Heidelberg: Springer Vieweg, 2013. https://doi.org/10.1007/978-3-642-41840-2

[8] F. Berner, B. Kochendörfer, and R. Schach, "Baubetriebsführung," in *Grundlagen der Baubetriebslehre 3, Leitfaden des Baubetriebs und der Bauwirtschaft*, Springer Vieweg, Wiesbaden, 2015, pp. 1–2, 2015. https://doi.org/10.1007/978-3-658-09038-8_1

[9] M. Evans and P. Farrell, "A strategic framework managing challenges of integrating lean construction and integrated project delivery on construction megaprojects, towards global integrated delivery transformative initiatives in multinational organizations," *Journal of Engineering, Design and Technology*, vol. 21, no. 2, pp. 376–416, 2023. https://doi.org/10.1108/JEDT-08-2021-0402

[10] M. Fiedler, Ed., "Lean construction – Das managementhandbuch," *Agile Methoden und Lean Management im Bauwesen,* 1st ed. Berlin, Heidelberg: Springer Berlin Heidelberg, 2018. https://doi.org/10.1007/978-3-662-55337-4

[11] S. B. Younis and D. A. Al-Kazzaz, "Scenarios of building information modelling-based design education in architecture schools," *International Journal of Engineering Pedagogy*, vol. 13, no. 8, pp. 51–66, 2023. https://doi.org/10.3991/ijep.v13i8.41303

[12] N. Bartels, "Strukturmodell zum datenaustausch im facility management", *Einleitung*, 1st ed. Wiesbaden: Springer Fachmedien Wiesbaden, pp. 1–5, 2020. https://doi.org/10.1007/978-3-658-30830-8_1

[13] A. Borrmann, M. König, C. Koch, and J. Beetz, "Building information modeling," *Technologische Grundlagen und Industrielle Praxis,* 2nd ed. Wiesbaden: Springer Fachmedien Wiesbaden GmbH, 2022. https://doi.org/10.1007/978-3-658-33361-4

[14] Fachhochschule Potsdam – University of Applied Sciences, *Forschendes Lernen am Fachbereich Bauingenieurwesen* [Accessed: Dec. 15 2023].

[15] P. Bychkov, I. Zabrodina, M. V. Netesova, and C. Mapelli, "Game-based learning while research activities of engineering students," *Int. J. Eng. Ped.*, vol. 8, no. 4, pp. 153–161, 2018. https://online-journals.org/index.php/i-jep/article/view/8126/5015

[16] C. Legner *et al.*, "Digitalization: Opportunity and challenge for the business and information systems engineering community," *Bus. Inf. Syst. Eng.*, vol. 59, pp. 301–308, 2017. https://doi.org/10.1007/s12599-017-0484-2

[17] Bundesingenieurkammer, Ed., "Ziele der Ingenieurausbildung und deren Einordnung in den deutschen Qualifikationsrahmen für lebenslanges Lernen. Positionspapier," *Bundes Ingenieurkammer* 2015. Accessed: Mar. 20 2024. [Online]. Available: https://bingk.de/wp-content/uploads/2015/07/Ingenieurausbildung2015_ansicht.pdf

[18] S. Loyens and R. Rikers, "Instruction based on inquiry," in *Educational psychology handbook series, Handbook of research on learning and instruction*, R. E. Mayer and P. A. Alexander, Eds., New York: Routledge Taylor & Francis Group, 2017, pp. 405–432.

[19] A. Scholkmann, "Forschend-entdeckendes Lernen: (Wieder-)Entdeckung eines didaktischen Prinzips," *Neues Handbuch Hochschullehre*, A 3.17, pp. 1–36, 2016. [Online]. Available: https://www.nhhl-bibliothek.de/api-v1/article/!/action/getPdfOfArticle/articleID/713/productID/10/filename/article-id-713.pdf

[20] L. Huber, "Warum Forschendes Lernen nötig und möglich ist," in *Forschendes Lernen im Studium*, L. Huber, J. Hellmer, and F. Schneider, Eds., Bielefeld: Webler, 2013, pp. 9–35.

[21] A. Daberkow, "Ein exploratives Lehrformat zur Elektromobilität im Kontext des forschungsorientierten Lernens," *Zeitschrift für Hochschulentwicklung*, vol. 15, no. 2, pp. 209–222, 2020,

[22] H. A. Mieg and P. Tremp, "Editorial: Forschendes lernen im spannungsfeld von wissenschaftsorientierung und berufsbezug," https://doi.org/10.3217/ZFHE-15-02/01

[23] B. Bloom, *Taxonomy of Educational Objectives*. London: Longmans, Green, 1956.

[24] J. Bortz and N. Döring, "Forschungsmethoden und Evaluation für Human– und Sozialwissenschaftler," 4th ed. Berlin, Heidelberg, New York, Tokyo: Springer, 2006. https://doi.org/10.1007/978-3-540-33306-7

8 AUTHORS

Niels Bartels studied at the Cooperative State University in Stuttgart and at the University of Wuppertal and completed his doctorate at the Institute of Construction Management at Technical University Dresden on the topic of "Structural Model for Data Exchange in Facility Management." Among other things, he worked as an innovation manager at Goldbeck GmbH, where he was responsible for smart building and projects for the digitalization of construction and the systematization of technical building services. Since 2022, he has been a professor for digital design and construction at the University of Applied Sciences Cologne (E-mail: niels.bartels@th-koeln.de).

Katrin Stolz is Head of the Department of Academic Teaching and Faculty Development at TU Dortmund University in Germany. She is engaged in the training and counseling of university teachers. Her research focuses on academic teaching and learning and the professionalization of academic development in Germany. She studied educational science in Düsseldorf and Cologne and received her doctorate from the University of Magdeburg.