# Quo Vadis? – Comprehensive Viewpoint on German Educational Research in Engineering

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***Abstract*—What are recent topics in engineering education research addressed by the German scientific community? What are current trends, loose ends, and open directions? Is the research conducted locally or in networks across institutions? Following these questions, we aim to seize the German research community's trends, research directions, and contexts. We survey a systematic literature review covering publications of German researchers published in education-related conferences and journals affiliated to IEEE between 2019 and 2022, resulting in 205 contributions in total. We analyze these works and illustrate results as contributions per topic, authors per institution, and the cross-work between institutions. The most prevalent topics turned out to be educational research, followed by curriculum design and remote instruction. Distinguishable, the German community also rehearse research for the K-12 level and develop Gamification techniques with the 18 % of contributions. Furthermore, we observe teams of three authors per contribution on average, and approximately 15 % of contributions are in collaboration among different institutions. On the basis of the literature review, we additionally provide our in-depth viewpoint discussing potential directions for German researchers and open a debate for best practices in supporting research on educational topics. We elaborate on effective means for promoting educational research in the community, more accessibility to learning technologies, and promotion of cross-work among institutions for further steeping the teaching research community within the IEEE.**

***Index Terms*—engineering educational research, teaching strategies, academia, STEM**

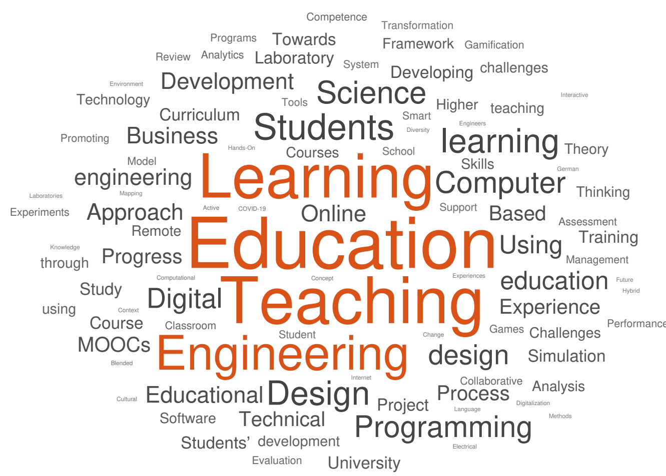


Fig. 1: World cloud from document titles published in IEEE Transactions on Education (ToE), IEEE Global Engineering Education Conference (EDUCON), IEEE Frontiers in Education (FIE), and IEEE German Conference on Education (GeCon) during 2019–2022.

## I. Introduction

Educational research aims for determining effective teaching methods and is thereby inherently a cornerstone for society's progress [2]. In order to fulfill this aim, educators have to track the fast-paced technical developments in industry and devise teaching methods and content to train students appropriately. For instance, the skills required in industry sectors like automotive industry, biotechnology, or information and communication technologies are developing so fast that curriculum planning is a challenge. Furthermore, there is also a growing demand for teaching professional skills next to purely technical concepts [3]. Multiple studies developed methodologies to merge science, technology, engineering and mathematics (STEM) topics with the liberal arts fields to facilitate critical thinking and creativity [4].

Contributing to the endeavor of educating the next generation of engineers, this paper explores research trends and practices in teaching by examining literature of German-affiliated researchers published during 2019–2022. In particular, we aim to answer the following research questions:

1) Which topics are addressed and what are trends, loose ends, and open directions?
2) Is the research conducted locally or in networks?
3) What are best practices that could support educational research?

While we answer questions 1) and 2) based on the literature review, we answer question 3) by providing our innermost viewpoint and open a debate for future directions.

We analyze publications in ToE, EDUCON, FIE, and GeCon, resulting in a total of 483 authors with 205 contri-

The authors are part of the IEEE Germany Section Executive Committee [1], currently in the following positions: Officer responsible for educational activities (Jorge Torres), officer responsible for university relations (Nicolai Spicher), and section chair (Jan Haase). Moreover, they were the organizing committee of the IEEE German Conference on Education (GeCon) 2022.

butions stemming from German institutions. As a preliminary overview, the word cloud in Fig. 1 visualizes keywords of publication titles, showing that majors are related to electrical engineering or computer science while topics like the internet of things, project-based learning, gamification, or remote teaching are highly researched.

In this study, we further analyze the research context, i.e., the institutions and projects where educational research is conducted. In addition, we evaluate the collaborative environment of the conducted research by examining the number of authors per paper and cross-work among different affiliations. This work also summarizes future research directions the community might follow and we give examples of unexplored topics, such as emerging technologies in education and laboratories designed for massive open online courses (MOOC).

The remainder of this work is structured as follows: In Section II we describe how we compiled the dataset by defining the literature databases for analysis as well as inclusion and exclusion criteria. We provide metrics and visualizations giving key results. We discuss our findings in Section III summarizing open research directions and opening a debate for organizational strategies to further support research in education. We give our innermost viewpoint for various topics, e.g., effective means for promoting educational research in the community, more accessibility to learning technologies, and promotion of cross-work among institutions. This could be a first step towards a road map for further educational research development and motivation for more educators to publish in the captivating field of education. Finally, we conclude the paper in Section IV.

## II. Scanning the Metrics

First, we describe how we constructed the dataset in Section II-A. Subsequently, we give results of our analysis, which we focus on two matters; teaching topics and research context in Section II-B and Section II-C, respectively.

### A. Compiling the Dataset

We acquired contributions published in three titles in IEEE Xplore [5] namely ToE, EDUCON, and FIE. We used the search command

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((("Publication Title":EDUCON) OR
("Publication Title":"Frontiers in
Education") OR ("Publication
Title":"Transactions on Education")
OR ("Publication Title":"GeCon")) AND
("Affiliation":Germany))
```

and filtering for the period 2019–2022, resulted in a total of 214 contributions. From this total number, we removed 9 works which were only slightly related to education, resulting in 205 contributions analyzed in this study. Following the recommendations by Gebru et al. [6], we document our dataset that we make freely available in [7].

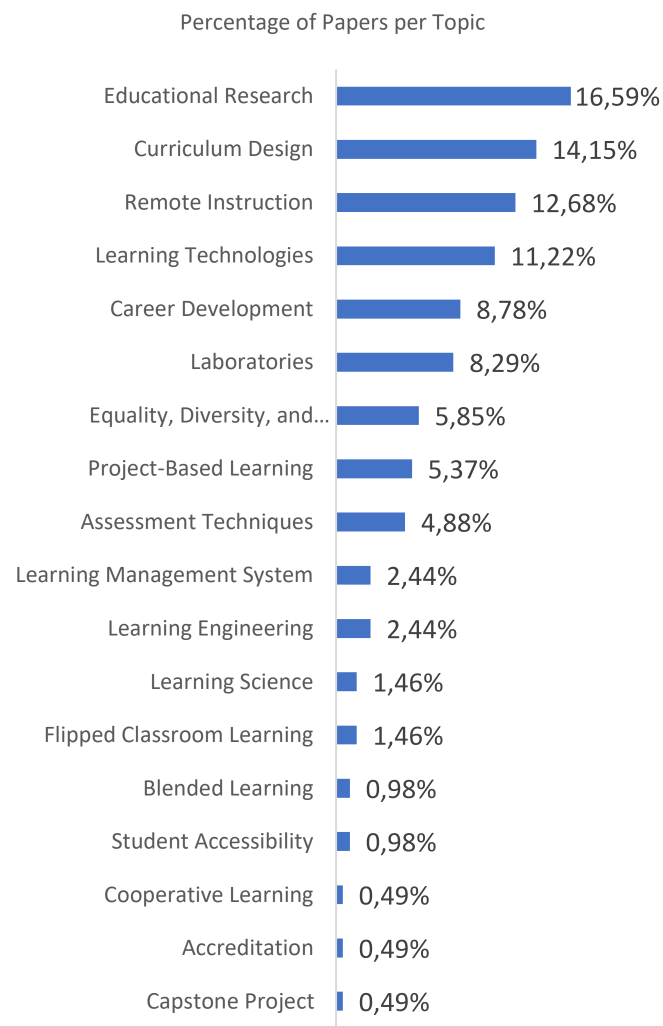


Fig. 2: Percentage of published papers per topic in ToE, EDUCON, FIE, and GeCon during 2019–2022.

### B. Analysis of Teaching Topics

Using the teaching topics defined by the IEEE Educational Society and Educational Activities [8] as a guideline, we classified the publications in 18 topics shown in Fig. 2. As can be seen, the three most common topics are educational research, followed by remote instruction, and curriculum design.

Fig. 3 illustrates the citations per topic in percentage. The most followed topics in the research community are Educational Research, Blended Learning, followed by Curriculum Design and Remote Instruction. Surprisingly, Blended Learning results in a highly cited topic despite the lower total of papers. The two examples are the blended methodologies combining various technologies in the field of artificial intelligence (AI), internet of things (IoT), and Biofeedback to reduce the drop-out rate of learners [9] and the use of flipped classrooms to improve the individual learning of students [10].

Providing more details on educational research, we observed that German researchers publish more systematic studies on

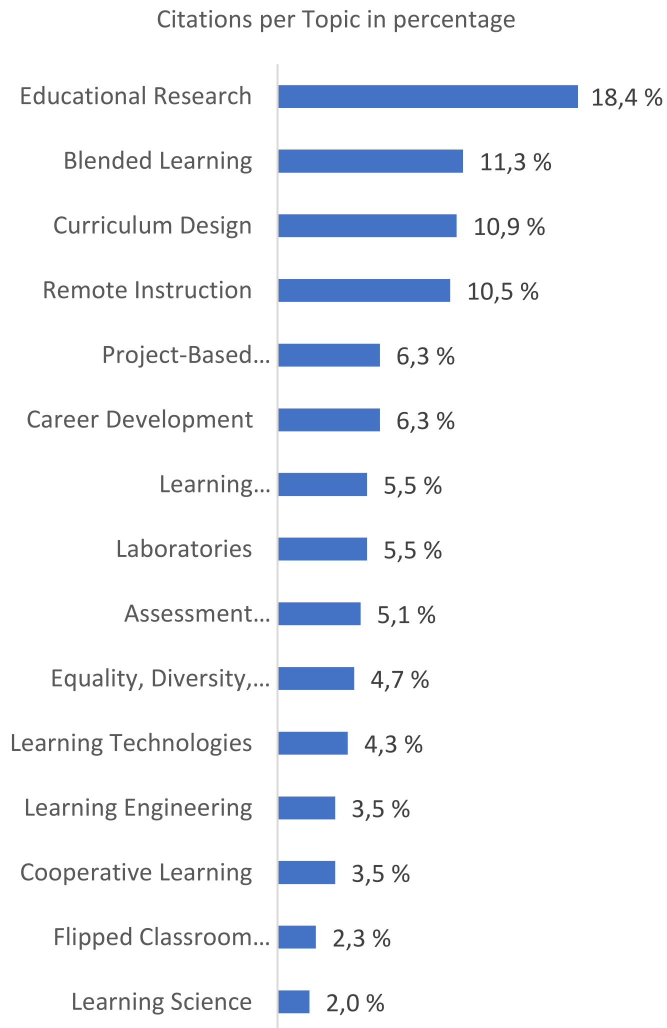


Fig. 3: Percentage of citations per topic in ToE, EDUCON, FIE, and GeCon during 2019–2022.

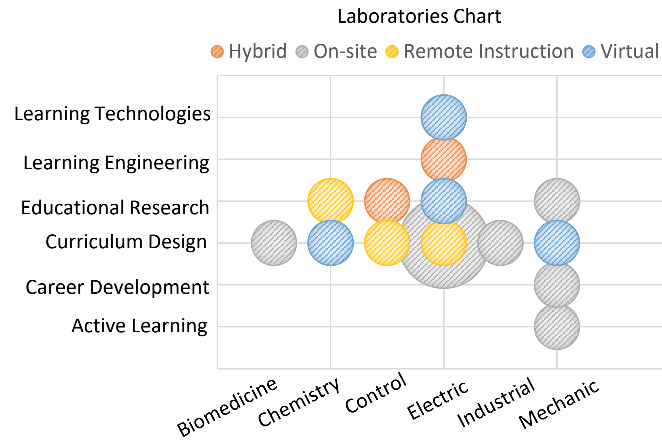


Fig. 4: Educational topics in laboratories with respect to curricula. Circle diameters represent the number of contributions.

how educators teach and less on how learners experience education or learn. Reports include i) the impact of the various online examination formats on the student's attitude, ii) new ways of teaching with senior students in the role of educators, or iii) motivation strategies attempting to improve the learning process, as illustrated in [11]–[13], respectively. In the curriculum design, researchers report teaching activities in specific fields, e.g., healthcare [14], how to teach core concepts in engineering and methods for educators' practices [15], and on the development of professional skills [16], [17]. Contributions related to remote instruction give information on systematic studies [18], [19], the design of teaching activities [20], and how to provide learning tools for MOOC with a focus on evaluation [21], [22].

Playing an essential role in technical careers, the design of laboratory experiments is also under study by the German community (approximately 12 %). The systematic study of its practices, analyzing the fulfillment of expected outcomes or the comparison between virtual and hands-on modalities are some examples, see for instance [23], [24]. Ambitious network projects such as Learning Management Systems and also supporting cross interactions between disciplines are also part of research as reported in [25].

Fig. 4 displays a bubble chart providing more details on the contributions related to laboratories and their modalities (on-site, virtual, hybrid remote instruction). Most of the contributions are related to curriculum design. The majority of works stem from the field of Electrical Engineering. In particular, laboratories' assignments are mostly reported for electrical engineering (52 %), followed by chemical and mechanical engineering (14 % each). The numbers for control and biomedical engineering are less. Regarding the modality, teaching is mostly conducted on-site (47 %) followed by remote instruction (26 %).

We also observed that much effort is put into methodologies like Gamification and teaching at the K-12 level with both representing around 18 % of papers. In particular, both fields of research are combined with eight other research topics which are shown in Fig. 5. Research on Gamification is focused on curriculum design and learning technologies, while studies for the K-12 level are reported in educational research topics and curriculum design. A combination of the two is also researched for school children's to jointly develop physical activities and educational content [26].

### C. Analysis of Research Context

We refer to the research context as the circumstances in which research is conducted. We investigate these issues by analyzing authors' affiliation, the total numbers of authors per contribution, and third-party funding.

A total of 483 authors at 109 institutions published in education topics in the analyzed time span. As can be seen in Fig. 6, the number of contributions and authors oscillates with high numbers in 2020 and 2022 and low numbers in 2019 and 2021. This might be explained by the COVID-19 pandemic.

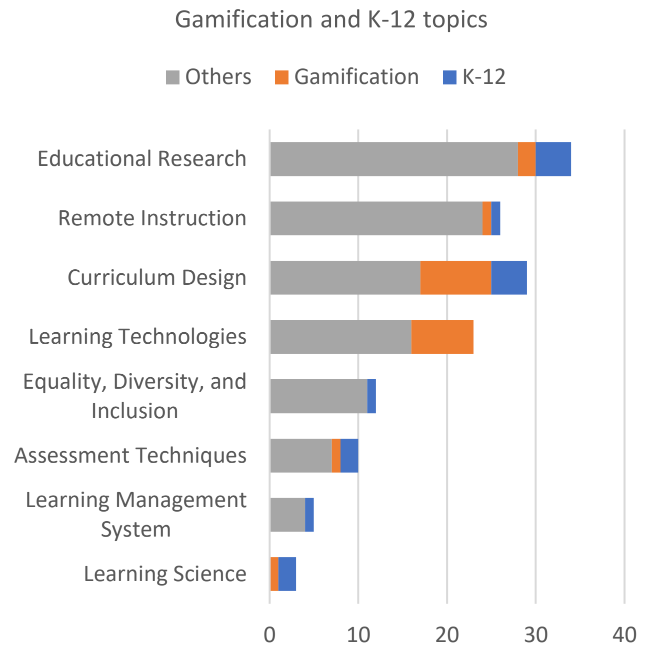


Fig. 5: Research topics of works related to Gamification and K-12 education.

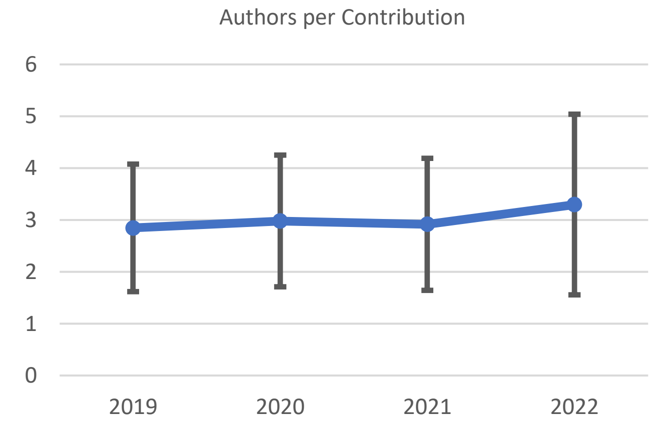


Fig. 7: Distribution of authors per contribution at ToE, EDUCON, FIE, and GeCon during 2019–2022. The horizontal bars represent the deviation around the average.

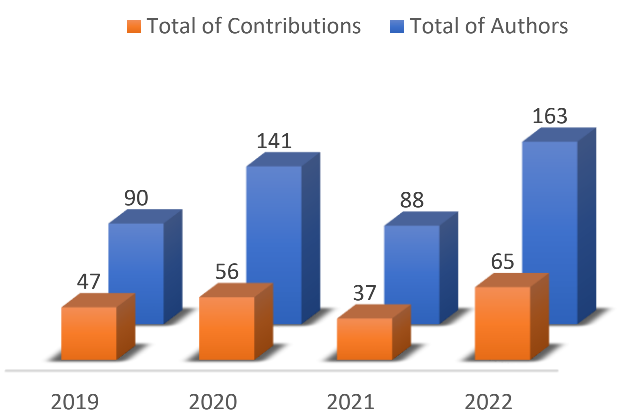


Fig. 6: Contributions and authors with respect to year at ToE, EDUCON, FIE, and GeCon.

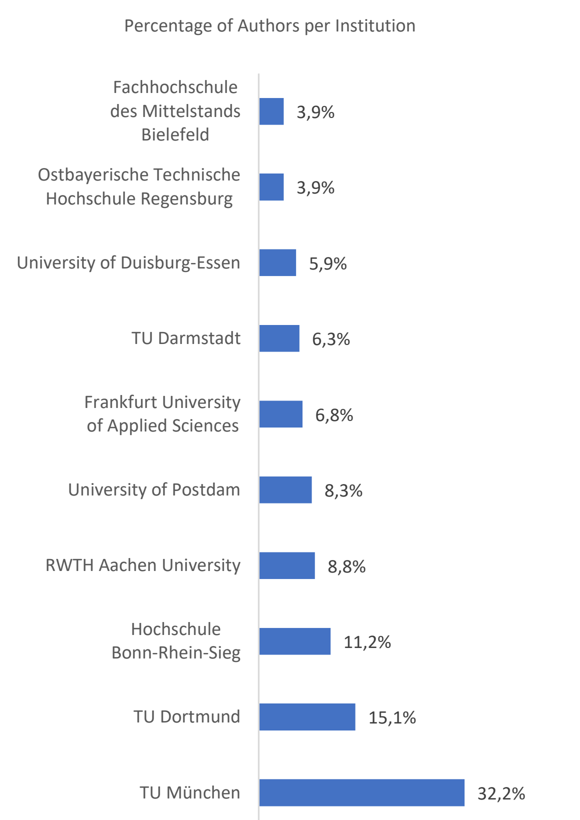


Fig. 8: Percentage of authors per institution publishing in ToE, EDUCON, FIE, and GeCon 2018–2022.

The distribution of authors per paper is displayed in Fig. 7. As can be seen, these numbers are rather stable in the analyzed time span with an increase in the year 2022. On average, German researchers team up with two co-authors. Fig. 8 summarizes the 10 affiliations publishing the highest number of works. As can be seen, there is a balanced distribution between Technical Universities, Universities, and Universities of Applied Sciences. The two most active institutions, TU Munich and TU Dortmund, are responsible for nearly 50 % of the published works.

On average, 15 % of papers come from more than one institution. Analyzing this aspect in more depth, Fig. 9 depicts

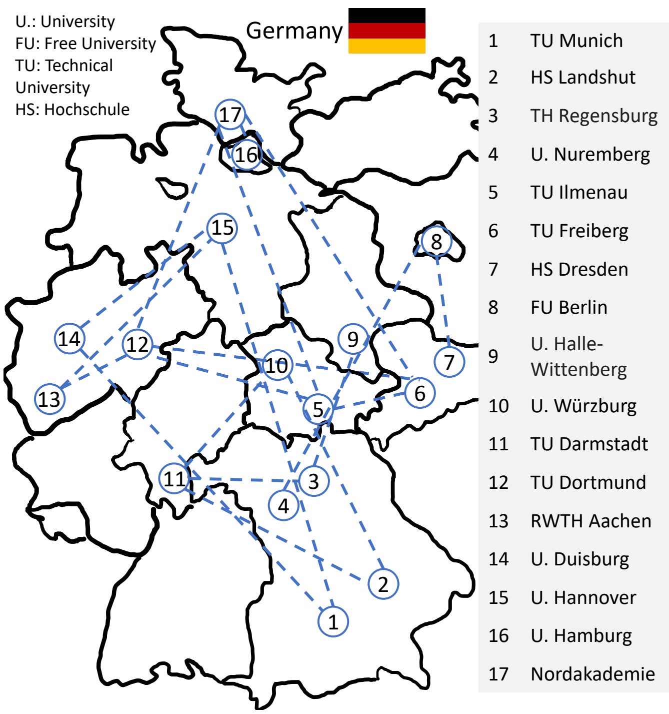


Fig. 9: Cross-work across different areas in Germany based on publications in ToE, EDUCON, and FIE 2018–2022.

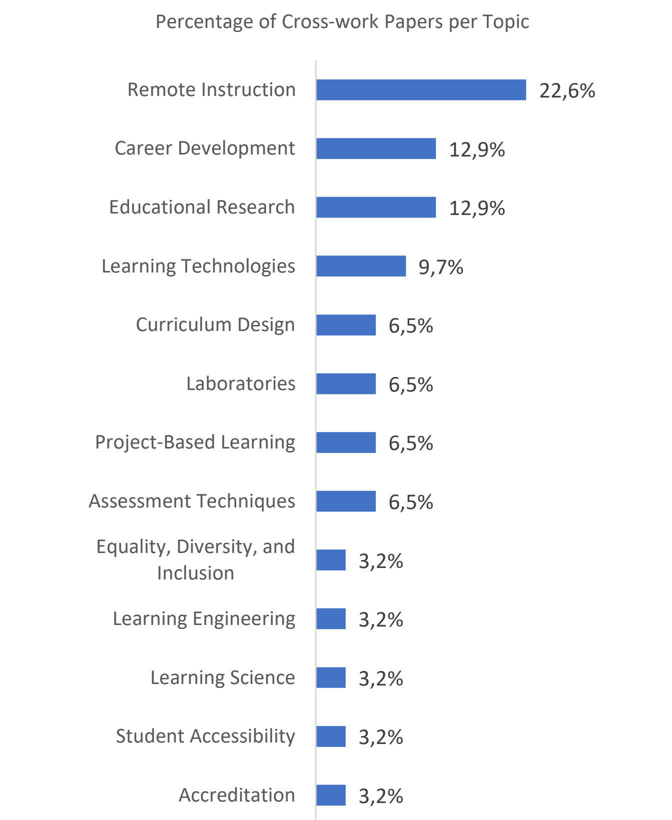


Fig. 10: Percentage of cross-work papers per teaching topics.

the connections between institutions across German states. These connections represent those institutions, as reported in the same published paper. As can be seen, the majority of connections are between two different institutions (76 %) and less among three (17 %) or four (7 %). Fig. 10 shows the topics and the corresponding contributions in percentage. When teaming up with other institutions most preferred directions are remote instruction [18], [20], [25], [27]–[30], followed by career development [31]–[34] and educational research [11], [23], [35], [36].

By analyzing the papers acknowledgment sections, we identified funding sources financing the works. Public agencies and academic institutions funded nearly the 30 % of research contributions. Most representative funding agencies were the German Federal Ministry of Education and Research (BMBF), followed by the Foundation for Innovation and University teaching, and the European Commission, as represented in Fig. 11. Specifically, Fig. 12 illustrates funding distribution along teaching topics. Most funded papers are related to curriculum design, followed by educational research and remote instruction. Table I summarizes funding agencies and projects with the corresponding links.

Among projects, we find topics like

- Digital and Remote labs development: DigiLab4U, ELLI 2, Crosslab.
- Teaching Training: Leibniz 4.0, SKILL.de.
- Curriculum design: Academic Education Initiative for Electric Mobility, software development in EVELIN, operational management of electric grids in digiFellows.
- Learning management systems: Automated competency measurement project.
- Learning Technologies: Erasmus+ Face-It, Go-Lab.
- Educational Research in the STEM learning: Informal spaces project.

## III. Future Outlooks and Viewpoints

The metrics displayed in the previous section reveal trends and open directions where educators may further advance new teaching methodologies. Furthermore, policymakers may build upon these results by directing programs and projects to benefit the educational community.

We discuss these viewpoints in two ways. The first targets the individual researcher, discloses trends, and potential research directions in educational research. The latter targets organizations and shows opportunities how to promote cooperative research among educators and how to establish favorable circumstances to advance research on educational topics.

### *A. Educator's outlook: Open Research Directions and Financial Opportunities*

The German research community contributes to various relevant topics in education. As illustrated in Figures 2 and 3, researchers particularly excel in four topics according to a high number of contributions and citations: Educational Research,

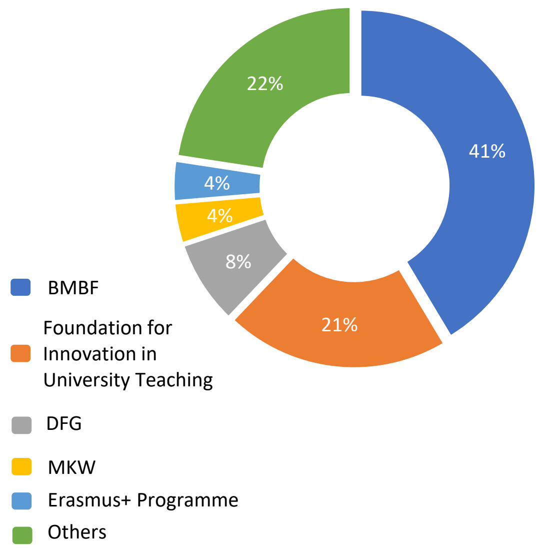


Fig. 11: Funding agencies based on information in acknowledgement sections. Acronyms for Funding agencies are German Federal Ministry of Education and Research (BMBF), German Research Foundation (DFG), and Ministry for Culture and Science of the state of North Rhine-Westphalia (MKV).

TABLE I: Funding agencies and projects

| Funding Agencies | Projects | Links |
|---|---|---|
| BMBF | DigiLab4U | [37] |
| | Academic Education Initiative for Electric Mobility Bavaria/Saxony | [38] |
| | EVELIN | [39] |
| | Excellent Teaching and Learning in Engineering Sciences (ELLI 2) | [40] |
| | Leibniz works 4.0 | [41] |
| | SKILL.de | [42] |
| German Donor Association | Crosslab | [43] |
| European Commission | Erasmus+ project Face-It | [44] |
| | Go-Lab | [45] |
| DFG | Automated competency measurement | [46] |
| State Government of North-Rhein-Westphalia | Fellowship for innovations in digital university | [47] |
| Ministry of Research and Culture of Lower Saxony, Germany | STEM learning in informal spaces | [48] |

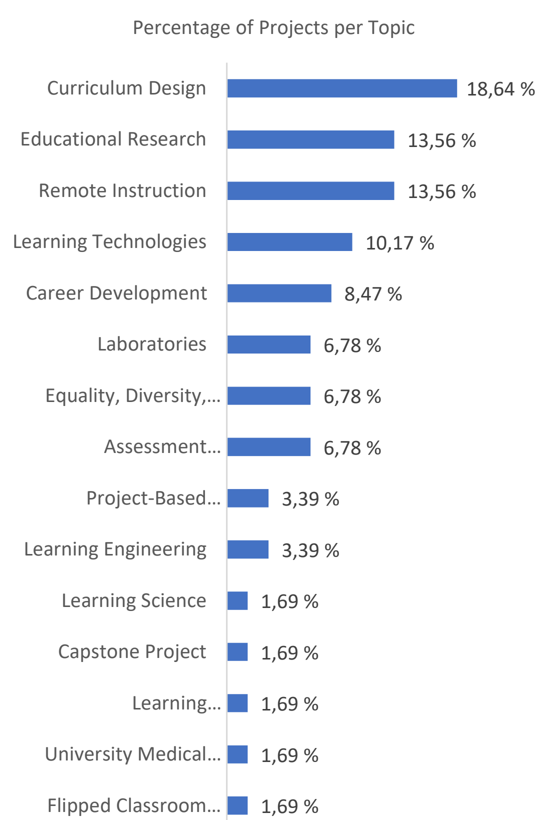


Fig. 12: Funded projects per teaching topics in the period 2018–2022.

Curriculum Design, Remote Instruction, and Blended Learning. Still, there are some research directions of high relevance which german researchers might contribute:

*1) Teaching research on emergent technologies:* Industry and research centers in Germany are rapidly deploying and addressing technologies still not covered sufficiently in education. For instance, cyber-physical system (CPS) for Industry 4.0, mobile networks, like 5G, 6G, or nanonetworks will demand new technical skills from developers and practitioners in the near future,[1]. Little research explicitly addresses teaching activities for novel related-topics like quantum communication, AI-enabled intelligent 6G networks, or molecular communications, where the German research community published more than 500 technical contributions in the last four years (cf. [51]).

Looking at contributions in teaching related to project-based learning in the period 2019–2022, we find teaching activities with machine learning to accelerate processing [52], electronic boards for humanitarian initiatives [53], computer and mobile networks [54], control systems in industry [55], programming for games developers [56], complex transmission systems in vehicles [57], software management for real-world problems [58], as well as 3D printing, robotics, and virtual reality [59]. Just one contribution refers explicitly to Industry 4.0 for developing management technologies as reported in [60]. Thereby, more research addressing emergent technologies is urgently required. New curriculum design can be reported, and educational research on best practices

[1]The 6G RIC project [49] is an example for a research project in 6G and Mamoko an example for nano-networks [50].

for teaching and learning can be developed following these emergent topics.

*2) Design of laboratories for MOOCs:* Remote instructions are a strong direction of German academics with the approximately 14 % of contributions and 10 % of citations (cf. Figures 2 and 3). Furthermore, the 50 % of contributions for labs are related to online and hybrid modalities. However, to the best of our knowledge, no recent literature in the German community is explicitly designing laboratory practices for MOOCs. Both topics, remote instruction and online labs, are strong directions and can be further advanced for designing labs in the challenging environment of MOOCs. Reported studies indicate the feasibility of large-scale experimental practices to some extent [61]; examples are given in electronics [62], and learning tools for dedicated programming languages [63]. Further potential extensions to the challenging environment of MOOC could be research based on remote practices with testbeds, as has been reported in chemistry [27], [64], electrical [65], [66], and control engineering [67].

*3) Teaching professionals and research skills jointly:* Typically, course content is focussed on technical skills for problem-solving, while less focus is on professional skills. However, curricula are working towards new teaching paradigms with the inclusion of competencies in the interception of knowledge and skills, such as collaboration and teamwork, communication skills, or writing skills [68, Sec. 4.2]. Not only professional skills are needed due to the rapid development of such technologies. Hence, literacy and research skills to stay up to date on the field need to be educated. In this regard, curricula where students acquire technical and professional skills jointly will be an expedient research direction. Further reading on the confluence of technical and professional skills is accessible in [69], [70].

*4) Multidisciplinary research:* Regarding, multidisciplinary projects, papers report typically only on single disciplines in a specific technical fields, e.g., computer science, electric, or chemical engineering. However, German universities already started to develop multidisciplinary centers for teaching across fields like bionic or human-machine interactions, see for instance the multidisciplinary education center at TU Dresden in [71]. The industry sector also develops quantum computing, quantum networks, or nanonetworks as multidisciplinary research directions. Teaching such topics in classrooms will require a multidisciplinary perspective. Thereby, more research is needed addressing teaching topics in a multidisciplinary way.

*5) Applying for financial support in engineering education:* Surprisingly, only approximately 30 % of works reported financial support by funding agencies. Considering financial opportunities, researchers might benefit from a range of IEEE programs directed to educational activities. For example, the professional and educational activities (PEA) committee within the IEEE Region 8, offers various programs supporting teaching activities, see [72]. Other examples are the $\alpha$-Engineering and TISP programs that promote STEM at the K-12 level by offering funding for workshop organization. Other programs are the Acceleration program to support teaching activities at K-12 or university level and continuing education. Another concept that might be suitable within education is the speaker program for keynote sessions in educational topics. Besides, the IEEE Germany Section awards travel grants to support the collaboration in teaching between two German academic institutions. This initiative promotes conducting teaching projects across universities, where students participate actively in reaching a technical goal, and supervisors enhance their experience in project-based learning methodologies [73].

### *B. Institutional outlooks: Incentive policies and actions promoting educational research*

Although there are IEEE programs promoting educational research, novel initiatives and actions could further advance research in education. We identified three major topics that we will discuss in details, namely financial initiatives, platforms for educational-tools development, and cross-work across institutions.

*1) Financial initiatives in Education:* From our point of view, more initiatives to support future research directions could be devised, showing up opportunities for educators. For instance, funding for participation in IEEE educational conferences like EDUCON, FIE, or GeCon for instance, for young researchers could further promote the conferences in the STEM research community. This could be realized by constituting a committee award selecting submitted contributions and fund the conference fees and accommodation for high-quality works. As typically, young researchers are funded for technical activities only, and are limited to participate in educational conferences. Such an initiative might motivate young researchers to conduct educational research.

*2) More accessibility to learning technologies:* IEEE offers some platforms supporting the exchange of lesson plans and data:

- The *TryEngineering* website [74] promotes lesson plans for K-12 levels which are accessible in various languages. Lessons exist for computer science, electronics, chemistry, aerospace, and mathematics.
- The *Teaching Excellence Hub* [75] provides material supporting teaching activities and readings.
- The *IEEEDataPort* website [76] allows to upload and share datasets, where researchers also submit data for educational research.

However, a portal to submit source code and apps for learning tools is lacking. As our results show that much material is being currently developed – around the 11 % address the development of learning tools (Fig. 2) – such a website could be a valuable asset. Some examples[2] are apps for augmented reality [77], simulator tools [78], [79], virtual labs [80], remote labs [81], machine learning [82], platforms for game-based learning [83], [84], digital twins for industrial environments [85], assembly of textual exercises [86], and assessment tools

[2]The list of contributions related to learning tools is accessible at [7]

[87]. Facilitating a web portal to share these tools allowing to collaboratively contribute to their code development will motivate researchers and educators to develop, share, and use these much-needed tools.

*3) Promoting research across educational institutions:* Cross-work among universities inherently leads to a stride forward in research and experiences from individual institutions. Integrating team skills and goals among universities will strengthen common research directions, explore new goals, and provide the opportunity to rehearse teaching at different auditoriums. In the German community, some research teams published along different regions and topics as can be seen in Figures 9 and 10. For example, the cross-lab project [43] is a valuable example of collaborative work in education. However, more collaborative projects could be promoted, leading to institutions organizing more networking sessions at conferences with this explicit plan. Typically, conferences offer technical sessions, keynotes, or tutorials, missing spontaneity and opportunity for attendees to build up networks. Dedicated sessions for networking can be organized to connect attendees and let them explore common research topics. Besides, funding programs could also positively evaluate joint activities across institutions which would lead to an increase in work between researchers of different affiliations.

## IV. Conclusion

In the last four years, German researchers in engineering educational topics, at IEEE conferences and journals, were focusing on remote instruction, career development, and academic research. Contributions were mostly written by three authors and, to some extent, in partnering between different academic institutions. Further research could be conducted to define teaching methodologies following the speedy steps of industry with a multidisciplinary approach, e.g., the design of virtual labs for MOOCs or novel ways to teach professional skills. Moreover we see potential for future initiatives to deepen research in education: From an institutional point of view, low-cost policies could be implemented to further promote educational research, e.g., funding for participation in IEEE educational conferences or for establishing partnerships across institutions.

## Acknowledgment

The authors want to thank Prof. Dr. Adam Wolisz and Prof. Dr. Falko Dressler (School of Electrical Engineering and Computer Science, TU Berlin, Berlin, Germany) for their valuable feedback on the paper content.

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