Project digiSTAR –
digital augmented Science Teaching and Research

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Abstract. This paper introduces the digiSTAR project, whose primary focus is on bridging the digital gap in undergraduate studies, which arises between the now digitalized schools and the technology-driven master's programs at universities when undergraduate courses are taught in a more traditional and less digitalized way, by providing teaching-learning modules and digital resources. The second goal is to provide pre-service science teachers with authentic learning opportunities for designing and testing lessons and (peer) feedback on their own developments, in accordance with the DiKoLAN framework, which characterizes digital competencies for teaching in science education. Initial results of the first design-based research cycle, based on a survey of first-year chemistry students, showed that chemistry students have difficulty understanding the physical fundamentals of quantum chemistry needed to understand topics such as molecular orbital theory. These challenges can potentially be eased through the implementation of innovative digital modules, which have been and will be created by teacher students enrolled in the Master of Education program. The project digiSTAR aims to establish a collection of digital modules designed for first-year science courses, with the long-term vision of extending this endeavour to encompassing a broader range of academic disciplines to address and reduce the digital gap.

1. Introduction
The COVID-19 pandemic has profoundly influenced and subsequently shifted the necessity for digitalization across all facets of life. This transformation was particularly apparent within educational institutions, as schools and higher education institutions, which were obliged to rapidly adapt digital teaching methods [1,2]. While these institutions had undergone partial digitalization in advance to the pandemic, this crisis exposed significant deficiencies in digital infrastructure [3] and, crucially, digital proficiency and literacy both for students and teachers [4]. This situation left all with no alternative but to bridge their knowledge gap through learning by doing [5]. Among the innumerable challenges that occurred during and after the pandemic, it has functioned as a catalyst for digitalization. Digital learning and teaching, including distance education, has become not
only possible but increasingly prevalent in various (educational) contexts. The impact of the pandemic extended beyond the sector of educational contexts. It highly influenced work environments such as science-related fields, where digitalization and digital literacy are no longer a mere choice but a necessity [6].

However, a clear disparity persists – a digital gap that needs to be addressed to ensure that the acquisition of digitalization-related competencies evolves a steady progression. Foundational courses at higher education institutions for science study programs, although now more digitally oriented than before the pandemic, still lack full digital embedding [7,8]. This deficiency affects all students enrolled in science programs, no matter if pursuing careers in digitalized research and academia areas or being in teacher education. Although both groups of students are expected to possess effective and innovative digital tool proficiency after graduation, they are not systematically in touch with or guided in the use of digital technologies during their undergraduate studies, nor are they given opportunities to use these skills independently. This digital literacy gap highlights the imbalance between the limited exposure to digital tool usage during their academic studies and the expectation of their proficient use upon completion of their education [9]. Bridging this digital gap between digitalized school education and the future digitalized work environment is essential to mitigate the digital literacy disparities experienced by students.

Figure 1 shows an exemplary selection of websites from various physics departments. In most cases, these sites also serve to promote the physics programs offered at the university. Certainly, the universities play with a classical-traditional image of physics, shown by images of handwritten formulas on a blackboard, which can be intuitively assigned to physics. Nevertheless, it can be questioned whether these representations might not also contribute to painting an outdated image of physics as a science in the general population as well as among first-year students. It can also be questioned why it is attractive to use representations of antiquated didactic approaches for advertising purposes and how large the overlaps with the later undergraduate lectures nevertheless are.

![Image](eth_zurich.png)

**Figure 1.** Sample screenshots of physics institute websites used to advertise physics degree programs (all taken on September 27, 2023) [10-15].

Promoting digital literacy and competencies among science students is essential, whether they are future educators or specialists in their field. This requires an ongoing process to ensure that they are fully prepared to use these tools effectively in their careers. Students pursuing careers as science educators, primarily Master of Education students, need to acquire essential competencies in using digital tools
while learning simultaneously how to instruct others how to use them optimally. These students require practical applications that are oriented towards real-world scenarios and must develop competencies in structuring, composing, and designing teaching and learning environments for their students.

2. Methods
The digiSTAR project (digital augmented Science Teaching and Research) is a collaborative project between the Biology Didactics (University of Kaiserslautern-Landau, RPTU), Physics Didactics (University of Konstanz, UKN) and Chemistry Didactics (UKN). The project has four main objectives. First, it aims to provide didactically sound teaching-learning modules for students in first-year science-courses. Secondly, it aims to provide didactically sound digital teaching-learning resources for use by lecturers and educators, together with didactic support to assist them in creating learning materials for their audiences. Thirdly, digiSTAR offers student teachers with science subjects in the Master of Education program authentic opportunities to learn how to operate digital technologies, to design and test their own digital teaching-learning modules, and to receive (peer) feedback on their own developments and teaching integrations. Additionally, these students are offered the chance to test their educational product, the learning-modules, in micro-teaching environments for immediate feedback from their peers. Finally, through the collaboration and the pooling of expertise between UKN and RPTU, digiSTAR aims to enhance the overall quality of education of students within the respective institutions.

Fundamentals for the development of didactically sound teaching-learning modules is encapsulated in the DiKoLAN framework (Digitale Kompetenzen für das Lehramt in den Naturwissenschaften, i.e. Digital Competencies for Teaching in Science Education, see Fig. 2) [16-18]. DiKoLAN serves as a regulatory framework that defines seven distinct essential digital competencies that students who are going to become science teachers, and science educators or lecturers in general, should possess when completing their academic studies. In essence, DiKoLAN serves as a comprehensive conceptual framework that outlines the critical digital proficiencies and literacy that educators must possess to effectively acquire and convey knowledge.

![DiKoLAN Framework](https://dikolan.de/en/) [18].
These competency areas are Documentation, Presentation, Communication/Collaboration, Information Search and Evaluation, Data Acquisition, Data Processing as well as Simulation and Modelling. DiKoLAN provides both educators and students with a structured framework, naming essential competencies to be acquired in each area. Within this project these areas will be used by students enrolled in a Master of Education program throughout their course of study, in line with the third main objective of digiSTAR, which is to provide comprehensive training in these areas as an integral part of their educational studies.

In order to achieve this goal, the competencies named and outlined in DiKoLAN are integrated into the curriculum at the UKN through a course designed for students enrolled in the Master of Education program, titled “Science Education III – Digital Competencies for Teaching in Science Education” (German: “Fachdidaktik III – Digitale Kompetenzen für das Lehramt in den Naturwissenschaften”). Within this course, students acquire a comprehensive understanding of the fundamental DiKoLAN competencies while engaging in self-assessment on their own skill sets [19, 20]. This educational program provides students both theoretical knowledge about digital literacy and competencies and practical experience with relevant and current research relevant tools (Fig. 3). The knowledge gained can be applied and practiced in educational settings, particularly in school contexts [19,20].

![Figure 3. Phase structure of the seminar [19, p. 3.]](image)

Following the progress of the project, since the summer term 2023, students enrolled in this particular course not only gained insights into DiKoLAN competencies and their application in educational settings, but also have the opportunity to develop teaching-learning modules for the digiSTAR project. These modules are intended firstly for students to practice their acquired digital knowledge and secondly for the use by instructors of first-year university courses in science study programs. Therefore, the digiSTAR project, the DiKoLAN framework and the course “Science Education III” are interlinked.

The project was initiated in winter term 2022/2023, and at the end of summer term 2023, half of the designated project duration has passed, with the project still for more than a year to go (Fig. 4).

![Figure 4. Project plan over the project duration of two years. The red triangle marks the project status at the time of writing this paper.](image)
The timeline of the project can be summarized as follows:

**First project semester (winter term 2022/2023).** Starting the project involved an initial examination of current pedagogical practices. Suitable questionnaires were created in collaboration with students and lecturers at both universities. Surveys were administered to both research and teaching oriented students to determine their digital needs, preferred areas of application, topics of interest for digital tools and modules, and their assessment of current deficiencies. This was initially carried out at the UKN as part of the undergraduate chemistry course and at RPTU as part of the undergraduate biology course. Based on the results of the survey, topics were identified for which students should receive supplemental assistance, which should therefore be prioritized in the development of digital add-ons. Furthermore, guidelines for the design of digital teaching-learning modules been formulated specifically for students in the Master of Education programs, based on current science education research [21-25] and the Cognitive Theory of Multimedia Learning [26].

**Second project semester (summer term 2023).** With the summer term of 2023, the project initiated its first design-research cycle. Students, enrolled in the Master of Education program, developed digital teaching-learning modules as add-ons to introductory lectures, focusing on topics identified in the survey. These teaching-learning modules will subsequently be integrated into the introductory lectures, allowing students to receive feedback on the quality and efficacy of their instructional materials.

**Third and fourth project semesters (winter term 2023/2024 and summer 2024).** Henceforth, during the winter term of 2023/2024 and the subsequent summer term of 2024, a second and third design-research cycle will be systematically executed and assessed.

**Project follow-up (winter term 2024/25).** The outcomes and findings from these cycles will be evaluated comprehensively in the winter term of 2024/2025.

During this process, the digiSTAR project working group will routinely assess a supplementary demand system for these first-year courses while maintaining a continuous collaborative effort between UKN and RPTU to fulfill the fourth main objective of the project.

3. Exemplary Results
The results of the initial survey of first-year students in introductory chemistry lectures before the initiation of the first design-research cycle reveal that students encounter the greatest difficulty with molecular orbital theory (MO-Theory), especially in the context of Linear Combination of Atomic Orbitals (LCAO).

For the planning, development and design of teaching-learning modules, students bear the responsibility of creating digital materials, incorporating elements such as Augmented Reality, simulation, and modeling software, or designing modules utilizing interactive units for tablets. With this, students are supposed to acquire digital proficiency and literacy (see DiKoLAN) in the construction of such modules, thereby preparing them for future roles as educators. The overarching objective was not only to make the learning process easier for the creators of these modules but also to introduce a wider range of digital resources into the first-year courses.

During “Science Education III”, a university course for students enrolled the Master of Education program of the UKN, students were tasked with designing and testing a teaching-learning module concerning the topic of MO-Theory and physics concepts underlying MO-Theory, e.g., the superposition principle. The learning-teaching module used a combination of the interference of two tones of the same frequency (and constant phase relation) generated by two loudspeakers and an augmented reality environment. Using the App Geogebra 3D the interference sound pattern which could directly be experienced by the loudness of the tone was calculated and visualized by a virtual overlay showing the loudness (Fig. 5). So, students could move through the room and compare experienced loudness and calculated loudness and thereby experience the effect of interference and at the same time
see the power of modelling in science. There is also the possibility for immersive interaction with this
modelling power by using the Augmented Reality function of the app [27-29].

Figure 5. Example product designed by students in the first design-based research cycle in summer
term 2023. A GeoGebra augmented reality application showing the loudness of the interference of two
tones of the same frequency at two position close to each other. Note that this is a first try of the students.
Hence, obvious shortcomings (e.g., the misrepresentation of sound waves as transverse waves) must be
corrected in a second design-based research cycle. The app is available at https://t1p.de/08vnt.

4. Discussion
As a result of the digiSTAR project, a collection of learning-teaching modules focusing on topics within
the first-year curriculum of introductory chemistry will be necessitated upon the completion of all three
design-research cycles. These materials will be made available to other higher education institutions, in
order to bridge the digital gap between academic science education and the later needed digital
competencies expected of science students in their future. Looking ahead, there are plans to extend the
coverage of digital teaching-learning modules to other first-year science courses, including those in
Biology and Physics.

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7. References

[10] Imperial College London, United Kingdom, https://www.imperial.ac.uk/study/courses/undergraduate/physics-theoretical-bsc
[22] Thoms L-J, Hoyer C and Girwidz R 2022 A Teacher Training Course on Using Digital Media for Acquisition, Visualization and 3D Printing of Complex Data and for Fostering Pupils’ Experimental Skills Physics Teacher Education ed J Borg Marks, P Galea, S Gatt and D Sands (Cham: Springer) pp 75–90