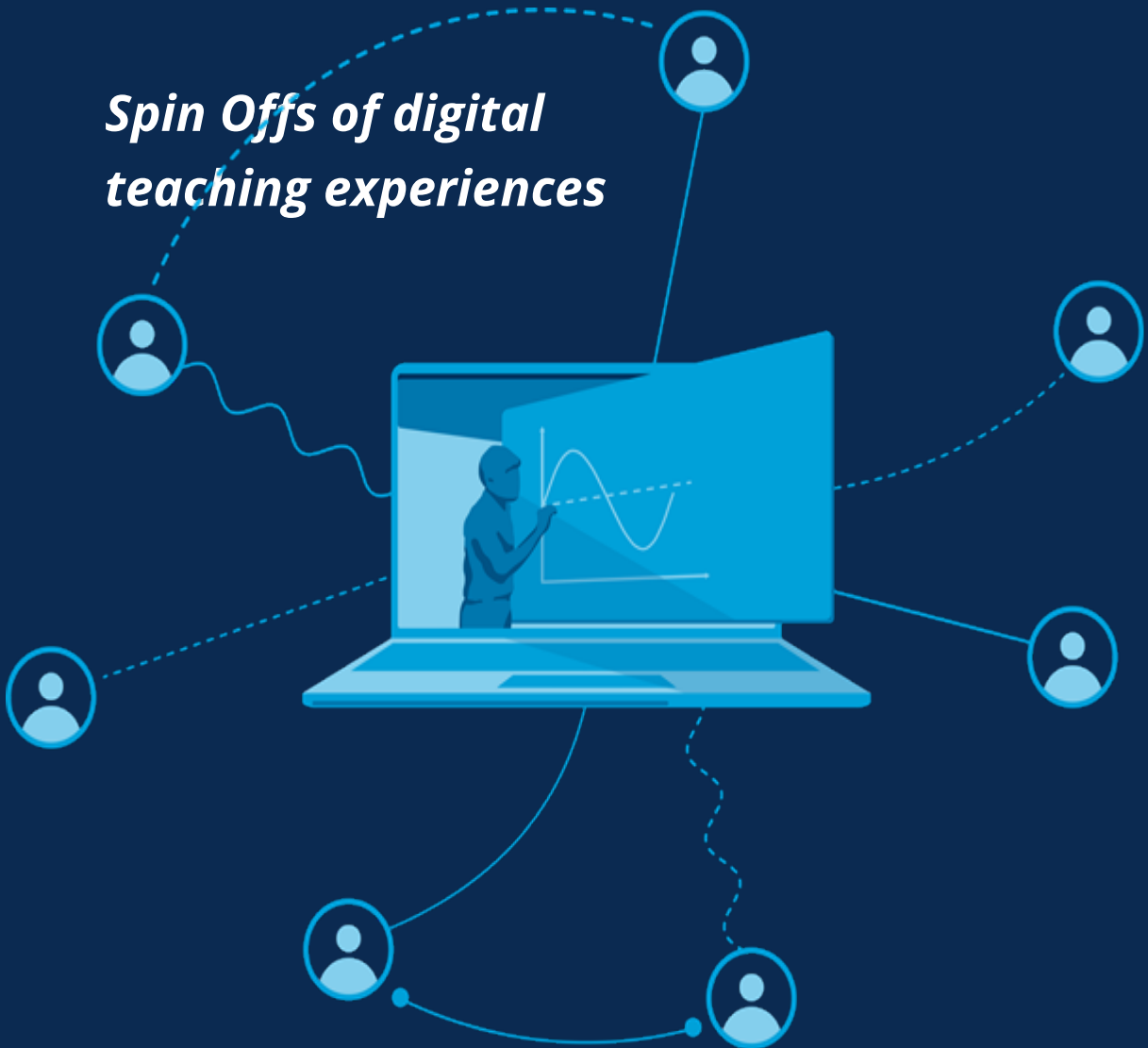


Lessons

Learned

*Spin Offs of digital
teaching experiences*



1

About the Journal

Due to the sudden and huge restrictions in face-to-face teaching brought about by the Corona pandemic starting with the summer term 2020, an unprecedented change and renewal of teaching formats has occurred. Even though these changes were forced by the restrictions due to the pandemic, the experiences and concepts that were developed are of enormous value for a renewal of teaching towards modern, digitally supported forms of teaching and learning and towards more competence-oriented learning. At the beginning of the winter term 2020/21, a conference entitled "Lessons Learned - Spin Offs of a Digital Semester" was held at the Faculty of Mechanical Engineering at the Dresden University of Technology to support this renewal through the exchange of experiences. A conference series has emerged from this first conference and at the same time the journal "Lessons Learned" was launched. The aim of this journal is to discuss new forms of teaching and learning not only in the mathematical and natural sciences and technical sciences, but far beyond in all subject disciplines and thus to create a platform where teachers can inform themselves about new concepts and adapt them for their own teaching.

The journal is deliberately published in two languages, both to make the experience gained accessible to an international audience and to ensure that the linked examples are accompanied by a text in the language of instruction in which they were produced. This means no additional work for the authors, as articles can be submitted in either German or English. Once an article has been accepted, the journal translates it into the other language, so that the authors only have to proofread the translated article.

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01069 Dresden

Editorial

With the present issue, Volume 5, Issue 1, **Lessons Learned** appears in principle later than originally planned. However, this timing is far less significant than it would have been in previous years. With our recent transition to a consistent **online-first publication model**, the emphasis has shifted from the release date of a complete issue to the timely publication of individual scholarly articles.

Online first primarily means one thing: **clear benefits for our authors**. Articles are published immediately after successful peer review and completion of the editorial process. They become visible, citable, and accessible without the need to wait for an entire issue to be finalized. This approach accelerates the dissemination of research results and allows contributions to enter scholarly discourse at an earlier stage, benefiting both authors and readers. The complete volume is then assembled organically, once all articles assigned to it have been published.

In this context, the later appearance of the present volume should not be understood as a drawback, but rather as the result of a more flexible and author-centered publishing process. **Lessons Learned** no longer follows rigid publication dates; instead, a volume is closed when it is complete in terms of content.

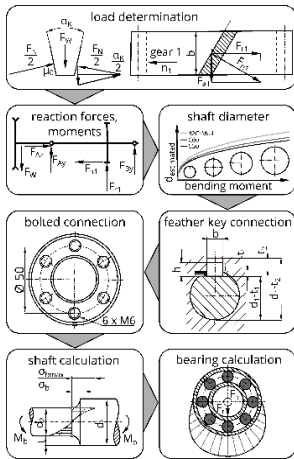
We are especially pleased to announce an important milestone for the journal's visibility and reputation: **Lessons Learned** has recently been accepted into the **Directory of Open Access Journals (DOAJ)**. Inclusion in the DOAJ recognizes our editorial standards, the transparency of our workflows, and our strong commitment to open access publishing. For authors, this means increased international discoverability and an additional level of quality assurance through a widely respected index of open access journals.

At the same time, we are already looking ahead. The next issue, Volume 5, Issue 2, will be created and published online in the coming days. It will be the **first thematic special issue of Lessons Learned**, marking an important step toward providing focused spaces for in-depth scholarly discussion. Like the current issue, it will be published entirely in online-first mode and will gradually take shape as individual articles become available.

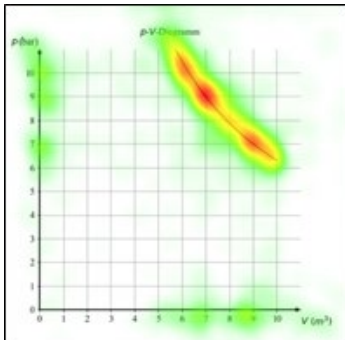
We thank all authors, reviewers, and readers for their continued trust and support. With these developments, **Lessons Learned** is well positioned to further strengthen its role as an open, visible, and contemporary forum for scholarly insights and reflective practice.

Stefan Odenbach

Range of topics



In this issue, we once again cover a wide range of topics, from the use of ChatGPT – an issue that is becoming increasingly relevant in teaching – to the establishment of student working groups and the quantitative recording of eye-tracking patterns to determine attention influences.



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Attempt of integrating ChatGPT into exercise classes of Theoretical Physics

A. R. Sprenger, A. M. Menzel*

Theory of Soft Matter / Biophysics, Institute of Physics, Faculty of Natural Sciences, Otto von Guericke University Magdeburg, Universitätsplatz 2, 39106 Magdeburg, Germany

Abstract

Integrating artificial intelligence (AI) at universities opens up new avenues for accessing and acquiring contents and methodological knowledge, as well as for managing academic work. We investigate the use of ChatGPT, an AI-powered chatbot, in the context of physics studies. Specifically, we focus on experiences in the exercise course for the introductory lecture on Theoretical Mechanics in the Physics Bachelor study program. Aspects beyond this course are addressed as well. Our approach includes additional exercises supporting the lectures that illustrate to students the potential and current limitations of ChatGPT in its freely available version. For this purpose, we used two different types of tasks. On the one hand, this involved using ChatGPT to solve computational exercises, and on the other hand, utilizing the chatbot for conceptual explanations of physical phenomena, definitions, and everyday examples. Additionally, we conducted an online survey among the students. The results show that students found the provision of conceptual explanations and examples by ChatGPT to be helpful. However, the support for computational tasks in the freely available version of ChatGPT at that time was perceived as unreliable and weak. Our framework contributes to the discussion on the meaningful use of AI technologies in university teaching and provides insights into students' perceptions and use of these technologies.

Die Integration von künstlicher Intelligenz (KI) in Forschung und Lehre an Universitäten eröffnet neue Wege für den Zugang zu und den Erwerb von inhaltlichem und methodischem Wissen sowie für die Bewältigung akademischer Arbeit. Wir untersuchen den Einsatz von ChatGPT, einem KI-gestützten Chatbot, im Kontext des Physikstudiums. Speziell konzentrieren wir uns auf Erfahrungen im Übungsbetrieb zur Physik-Bachelor-Grundvorlesung Theoretische Mechanik. Auch weitergehende Aspekte werden erfasst. Unser Ansatz beinhaltet die Einbindung von zusätzlichen, vorlesungsbegleitenden Übungsaufgaben, um den Studierenden das Potenzial sowie die aktuellen Limitationen von ChatGPT in der frei verfügbaren Version zu verdeutlichen. Hierfür setzten wir zwei verschiedene Arten von Aufgaben ein. Einerseits war dies die Verwendung von ChatGPT zur Lösung rechnerischer Übungsaufgaben, andererseits die Nutzung des Chatbots für konzeptionelle Erklärungen physikalischer Phänomene, Definitionen und Alltagsbeispiele. Zusätzlich führten wir eine Online-Umfrage unter den Studierenden durch. Die Ergebnisse zeigen, dass die Studierenden die Bereitstellung von konzeptionellen Erklärungen und Beispielen durch ChatGPT als hilfreich empfanden. Allerdings wurde die Unterstützung bei rechnerischen Aufgaben in der zu diesem Zeitpunkt frei verfügbaren Version von ChatGPT als unzuverlässig und schwach empfunden. Unser Ansatz trägt zur Diskussion über den sinnvollen Einsatz von KI-Technologien in der universitären Lehre bei und liefert Einblicke in die Wahrnehmung und Nutzung dieser Technologien durch Studierende.

*Corresponding author: a.menzel@ovgu.de

This article was originally submitted in German.

1. Introduction

The development of AI-powered chatbots marks a significant technological milestone. When OpenAI released its chatbot, ChatGPT, to the public for free on November 30, 2022, one million users worldwide registered within a few days. Since its launch, a remarkable transformation has been felt in various areas of our society, including education. AI-powered chatbots have the potential to support and improve the teaching and learning process.

At universities, especially in teaching and studying, the integration of such technologies holds both great potential and some challenges. On one hand, the use of ChatGPT provides students with new access to knowledge, both in terms of content and methodology, and facilitates the completion of academic tasks through the immediate availability of information and explanations. On the other hand, there are also risks, such as the possibility of dependence on the technology and the danger of spreading inaccurate or even false information. Physics, and theoretical physics in particular, uses mathematical expressions to quantitatively describe content. The question arises to what extent this can currently be represented by ChatGPT.

Our approach in the first attempts to integrate ChatGPT into the teaching and learning of theoretical physics includes the integration of the chatbot into additional, lecture-accompanying exercises. We aim to show students both the potential and the limitations of this technology in its current state at the time of use. To this end, we focus on two types of exercises. On one hand, ChatGPT will be used to solve computational exercises. On the other hand, the chatbot will be employed to find conceptual explanations of physical phenomena, definitions, and everyday examples.

The structure of this article is as follows. First, we explain in detail how ChatGPT was integrated into the exercise class and which different types of exercises were set. We then present the results of an online survey conducted among the students to evaluate their experiences and perceptions regarding the work with ChatGPT. Finally, we summarize and draw con-

clusions about the effectiveness and challenges of using ChatGPT in physics studies. Finally, we give an outlook on possible future developments and improvements in the integration of AI-based technologies within the framework we have described.

2. Use of ChatGPT in the study of theoretical physics

We investigate the use of ChatGPT, an AI-supported chatbot, in the context of physics studies, specifically in the field of theoretical physics. Our approach includes the integration of lecture-accompanying exercises to show students both the potential and the limitations of ChatGPT in the version freely available at the time of the report. We gained our experience during the lecture on theoretical mechanics in the winter semester 2023/2024, when students had free access to ChatGPT version GPT-3.5 [1]. We did not require students to register with ChatGPT. The course on theoretical mechanics, to which we refer, is part of the bachelor degree program in physics at Otto von Guericke University Magdeburg [2] and is a compulsory course in the third semester.

In the lecture (four hours per week during teaching periods) the basics of theoretical mechanics are developed. The course content and associated calculation techniques are introduced and taught step by step. An essential component of the courses is given by the accompanying exercises. Here, students learn and practice how to carry out complex calculations independently. Each week, students receive an exercise sheet with four calculation exercises, parts of which are corrected and assessed after being submitted online. We use a digital process via an e-learning platform [3] for submission of the solutions to the exercises and to correct them. The discussion takes place in person. In the associated course (two hours per week during teaching periods), the solutions to the exercises on each exercise sheet are discussed.

In addition to the regular analytical calculation exercises described above, we added a short, fifth ChatGPT exercise to each exercise sheet. This exercise referred either to the current ex-

ercises on the sheet or to the current lecture content. We used two types of exercises. On one hand, students were asked to solve simple problems of calculation related to the lecture. First, they solved this exercise independently by themselves, then they asked for help by ChatGPT. On the other hand, the students were asked to use the chatbot to obtain conceptual explanations of physical phenomena, definitions, and everyday examples. To briefly summarize the result: while the chatbot can provide reliable explanations of physical phenomena and concepts, errors regularly occurred when processing calculation exercises in the described framework in the version freely available at the time of report. Explanations were imprecise so that misunderstandings were virtually unavoidable. In some cases, it was very difficult or practically impossible to obtain correct calculation solutions, even with intensive discussion and assistance. The ChatGPT exercises were completed on a voluntary basis and were not included in the assessment of the students' performance in the corresponding module.

In the following, we present examples of the two types of exercises. The functionality of the chatbot in this context is discussed on the basis of its output.

We start with an example for a calculation exercise. The ChatGPT exercise refers to another exercise on the first exercise sheet that the students beforehand solved by conventional, analytical calculation (e.g. with paper and pencil). In the following, we first reproduce the wording of the **conventional calculation exercise** and then the wording of the related **ChatGPT exercise**. We then insert a typical **user input** to obtain the solution to this exercise using ChatGPT. We reproduce the **chatbot output**. Later, we classify the result under **Conclusion/Criticism**.

Wording of the conventional calculation exercise 4(d) (translated from German): Use index notation (including Einstein's summation convention) and the totally antisymmetric third-rank tensor with components ε_{ijk} to compute the following expression:

$$\vec{a} \cdot (\vec{b} \times \vec{a}) \quad (1)$$

Wording of the related ChatGPT exercise (translated from German): Try to elicit the

calculation of exercise 4(d) from ChatGPT. Then check the calculation. Please upload your chat history for solving exercise 4(d) together with the solution of the exercise sheet to the e-learning portal.

User input (translated from German): Please calculate and simplify $\vec{a} \cdot (\vec{b} \times \vec{a})$ using Einstein's summation convention.

Chatbot output (translated from German): To calculate and simplify the expression $\vec{a} \cdot (\vec{b} \times \vec{a})$ using Einstein's summation convention, we proceed as follows: First, we use the identity for the cross product in vector form:

$$(\vec{b} \times \vec{a}) = \varepsilon_{ijk} b^j a^k \hat{e}_i \quad (1)$$

Here ε_{ijk} is the Levi-Civita symbol and \hat{e}_i are the unit vectors. Now we multiply \vec{a} by the result of the cross product:

$$\vec{a} \cdot (\vec{b} \times \vec{a}) = a^i (\vec{b} \times \vec{a})_i \quad (2)$$

Let us insert the cross product:

$$(\vec{b} \times \vec{a})_i = \varepsilon_{ijk} b^j a^k \quad (3)$$

Then we get:

$$\vec{a} \cdot (\vec{b} \times \vec{a}) = a^i \varepsilon_{ijk} b^j a^k \quad (4)$$

Since ε_{ijk} is antisymmetric (i.e. $\varepsilon_{ijk} = -\varepsilon_{ikj}$), we can rearrange:

$$\vec{a} \cdot (\vec{b} \times \vec{a}) = \varepsilon_{ijk} a^i a^k b^j \quad (5)$$

Now we use Einstein's summation convention to sum over i and k :

$$\vec{a} \cdot (\vec{b} \times \vec{a}) = \varepsilon_{ijk} a^i a^k b^j = a^i a^k \varepsilon_{ijk} b^j \quad (6)$$

Since $\varepsilon_{ijk} a^i a^k = 0$ (because ε_{ijk} is only nonzero if i, j, k are different indices), it follows that

$$\vec{a} \cdot (\vec{b} \times \vec{a}) = 0 \quad (7)$$

Therefore, the simplified formula for $\vec{a} \cdot (\vec{b} \times \vec{a})$ using Einstein's summation convention is 0.

Conclusion/Criticism: This issue is a prime example of the problems that can arise when using ChatGPT for calculation tasks. In this case, the AI-supported chatbot arrives at the correct final result, but the reasoning is incorrect and therefore not reliable.

In the fourth calculation step (between equations 4 and 5), ChatGPT justifies the rearrangement of the terms by the Levi-Civita symbol being antisymmetric. However, the actual reason lies in the fact that a^i, a^k , and b^j are individual indexed vector components, that is, simple numbers in this specific case. The multiplication of simple numbers is commutative, which

means that we can change the order of multiplication at will.

Another problem can be found in the last calculation step (between equations 6 and 7). The chatbot statement is that the expression $\varepsilon_{ijk} a^i a^k$ becomes zero because the Levi-Civita symbol is only nonzero if all indices are different. However, recalling Einstein's summation convention, contributions containing different indices actually do occur in this expression. In general, these contributions do not vanish. The actual reason for the result being zero is that the contributions pairwise cancel each other. Now, the background is that the Levi-Civita symbol is antisymmetric, which is the reasoning that was incorrectly used between equations 4 and 5.

To summarize, the chatbot has managed to list the definitions of the expressions correctly. It also reproduces the correct result. However, the calculation is not correct if one follows the logic of the incorrectly displayed justifications. Errors occur when it comes to correctly combining individual properties of the employed variables and generating a logical justification and derivation.

Next, we present an exemplary ChatGPT exercise on conceptual explanations following the same pattern:

ChatGPT exercise (translated from German): Have ChatGPT list the defining characteristics of conservative force fields. Then evaluate the outputs. Please upload your chat history together with the solution of the exercise sheet to the e-learning portal.

User input (translated from German): Please list all required/defining characteristics of conservative force fields.

Chatbot output (translated from German): A conservative force field has several characteristics that distinguish it from nonconservative force fields. Here are the most important characteristics:

1. Conservative forces depend only on position: In a conservative force field, the force acting on a particle depends only on its position and not on its velocity or time. This means that the force is independent of the movement of the particle.
2. Work is independent of the path: The work performed by a conservative force on a parti-

cle depends only on the initial and final positions of the particle and not on the exact path that the particle takes between these two positions. This is called path independence.

3. Conservation of energy: In a conservative force field, the mechanical energy of a particle is conserved. This means that the sum of kinetic energy (energy due to velocity) and potential energy (energy due to position in the field) remains constant as long as no nonconservative forces (such as friction) are acting.

4. Potential energy: A potential energy can be defined in a conservative force field. This potential energy depends on the position of the particle in the field and can be used to calculate the work performed by the force on the particle as it moves between different positions.

5. Closed paths: In a conservative force field, the work performed along a closed path (a closed loop) is always zero. This means that energy is conserved when a particle moves along a closed path.

These characteristics are crucial for understanding conservative force fields in physics. They make it possible to understand the conservation of energy and the relationship between forces, potentials, and paths in conservative fields.

Conclusion/Criticism: In this case, ChatGPT manages to provide a comprehensive and detailed answer. If further questions are asked, the individual points are also presented as formulas. One point of criticism could be the failure to mention the vanishing curl of the force field, at least if the force field is defined in a simply connected space. ChatGPT does not list these points in the first answer. However, they can be generated upon further inquiry. Furthermore, it is not clear which properties are actually defining. For example, point 1 describes a property, but does not define a conservative force field. In contrast, point 2 is sufficient in itself as a definition of a conservative force field. Without wishing to criticize the user at this point, the above observation also allows us to draw possible conclusions about how to improve the design of the input. The combination of the not completely synonymous terms "required" and "defining" with the help of the slash "/" may suggest a synonymity that is not

completely true and influences the less differentiated output of the results.

In summary, we may say that ChatGPT can well be used to provide explanations of physical phenomena and concepts. This is especially true when no in-depth description using mathematical formulas and logical linking of calculation steps is required. In contrast, errors, imprecise reasoning, and misunderstandings regularly occur when working on calculation problems in theoretical physics. This trend was observed across all ten ChatGPT exercises set during the semester. Half of them contained calculation problems, while the other half required conceptual points and explanations.

3. Assessment by the students

In order to obtain more detailed feedback and assessment of the results from the students, we conducted an anonymous online survey at the end of the lecture period of the winter semester 2023/2024 via the e-learning platform [3] of the Otto von Guericke University Magdeburg. Responses were provided by nine participants. The trends resulting from this survey are presented and discussed below.

Questions were asked about the frequency of previous and expected future use and the estimated usefulness of ChatGPT for various tasks and requirements. Some of these questions related specifically to the study of theoretical physics, some related to the study of physics in general, and some went further beyond. All questions could be rated on a scale from 1 to 8. The two end points of the scales were verbalized, according to the question. The value 1 expressed the minimum in terms of the lowest level of agreement, most negative attitude, or minimum frequency. The value 8 corresponded to the maximum in terms of the strongest agreement, most positive attitude, or maximum frequency. The students were informed that our scale does not have an indifferent mean value, so that the rating 4 tends slightly towards 1, and the rating 5 tends slightly towards 8.

In general, our aim in including the ChatGPT exercises was to motivate students to experience the possibilities and current limitations of the new technology. On one hand, this relates to the context of their studies. On the other

hand, we also wanted to stimulate them in general to keep an eye on technological developments and to engage with them. Accordingly, the aim of our survey was not only to find out how the students perceived the usefulness of ChatGPT in the narrow technical and methodological context of the ChatGPT exercises described above. We also wanted to find out whether we had succeeded in sensitizing the students in general with regard to possible further use of ChatGPT in physics studies and beyond. We also intended to find out in general how much the students liked our approach of introducing them to the technology in this way. Out of the participating students, all stated that they had used ChatGPT occasionally to frequently in the past. None of them used ChatGPT for the first time.

With regard to the two different types of ChatGPT exercises presented above, we asked the students to rate the usefulness of ChatGPT, see Fig. 1. At the time of processing and survey, version GPT-3.5 was available free of charge.

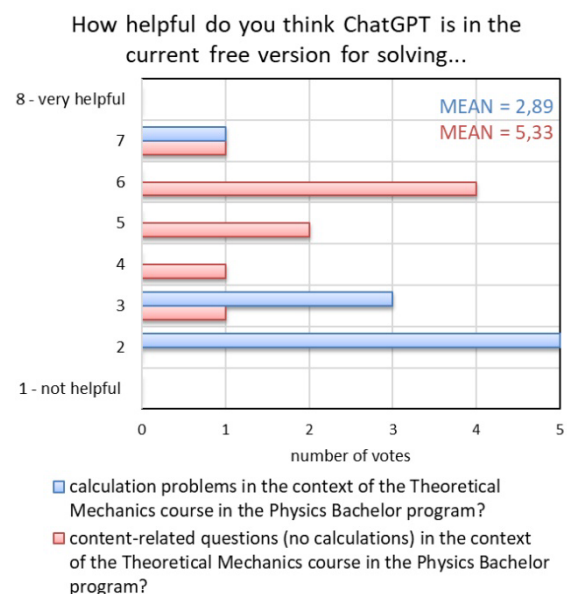


Fig. 1: Students' assessment of the usefulness of ChatGPT for solving calculation problems and clarifying questions referring to the compulsory course Theoretical Mechanics in the bachelor degree program in physics. At the time of the survey, version GPT-3.5 was freely available.

The majority of students found the use of ChatGPT for solving calculation problems to be less helpful, see the blue bars in Fig. 1. In contrast, the majority of participating students rated its use for clarifying content-related

questions as positive, see the red bars in Fig. 1. These two trends are consistent with our own experience of using the version GPT-3.5.

Next, we wanted to determine to what extent the students plan to use ChatGPT in the future as part of their further physics studies after dealing with ChatGPT when working on our exercises, and in other, for example private contexts, see Fig. 2. Unsurprisingly, based on the described experiences, uniformly the students rarely plan to consult the chatbot for help with calculations in theoretical physics, see the blue data in Fig. 2. With regard to assistance with general physics content, students are slightly more likely to consider future use in theoretical physics, see the red bars in Fig. 2.

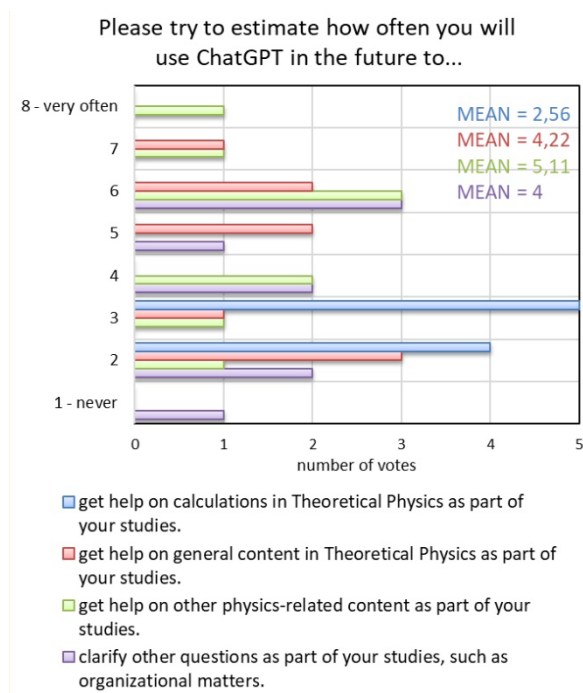


Fig. 2: Students' assessment of the frequency with which they would use ChatGPT in the future as part of their studies. We distinguish between calculation exercises and content-related questions in theoretical physics, as well as content-related and organizational questions in the remaining context of their studies.

In contrast, there is a more positive attitude towards use concerning more general aspects of their studies, see the green bars in Fig. 2. We suspect that theoretical physics occupies a different position here with regard to the prevailing mathematical language and expressions than subject areas that are primarily communicated in a verbal way. This is also consistent

with our earlier finding that, mostly, students in theoretical physics still prefer a handwritten approach [4]. It may suggest that students are more likely to consider the technology in other areas such as experimental physics. The future tendency of referring to ChatGPT was rated as moderate on average concerning other questions within the context of the courses, for example, organizational issues, see the purple bars in Fig. 2.

In contrast to skills of calculation, at the time the online survey was evaluated, AI-supported chatbots had great potential in processing and writing texts. Accordingly, ChatGPT could be a great help, particularly when writing academic texts, especially in seminar tasks, bachelor and master theses.

In this context, it was interesting for us to find out how often the students expected they would use ChatGPT in the future when writing such academic texts, see Fig. 3. It is very surprising to us that, on average, the students can only imagine using ChatGPT with moderate frequency as support for academic writing, see the red bars in Fig. 3.

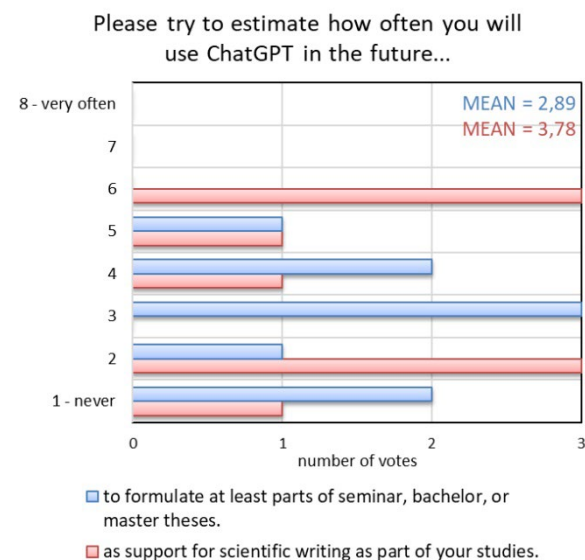


Fig. 3: Students' assessment of the expected frequency of using ChatGPT when writing scientific texts as part of their studies. The results distinguish between academic writing specifically in the context of seminar tasks, bachelor and master theses on one hand, and remaining, more general writing on the other hand.

In the context of physics studies, this category could include, for example, the writing of parts

of lab reports or descriptions and evaluations of experiments. This is all the more surprising as students repeatedly report in personal discussions about the high workload associated with writing such texts.

The intention to use ChatGPT specifically for formulating parts of seminar tasks and theses is even less apparent, which in the context of physics studies particularly concerns bachelor and master theses, see the blue bars in Fig. 3. On one hand, this may be due to third-semester students still feeling that writing their bachelor thesis is a long way ahead. On the other hand, it could result from fear and uncertainty about violations of declarations of independence, that is, the declaration that the thesis was written without any aids other than those specified. This context generally points to the urgency of clarifying the relevant facts and making them widely known, if possible using concrete examples. In other words, clear regulations are required in this case as to when the use of AI-supported tools is permitted, in what form, and under which circumstances. Teachers can use such regulations to educate students how to use new technologies and gain confidence in assessing their performance. Students can learn how to use the technologies profitably within this framework.

Another area of potential use concerns the general linguistic capabilities of ChatGPT in the context of writing computer programs and translating texts. These tasks apply to the learning of foreign and programming languages. ChatGPT can be helpful in creating simulation code and in finding and correcting programming errors. In contrast to conventional translation software, ChatGPT can potentially provide more coherent translations for longer texts. In the context of the lecture on theoretical mechanics, these applications are only marginally relevant. However, the chatbot could support the writing of research-relevant simulation code during the master thesis at the latest. It could also be helpful for better understanding of scientific literature when translating it from English, or when writing the bachelor or master thesis in English. Accordingly, in Fig. 4 we show the frequency with which students estimate they have consulted the chatbot in the past and will consult it in the future

for these and similar purposes. It can be clearly seen that the majority of participants have rarely or never used ChatGPT for programming assistance, see the blue bars in Fig. 4.

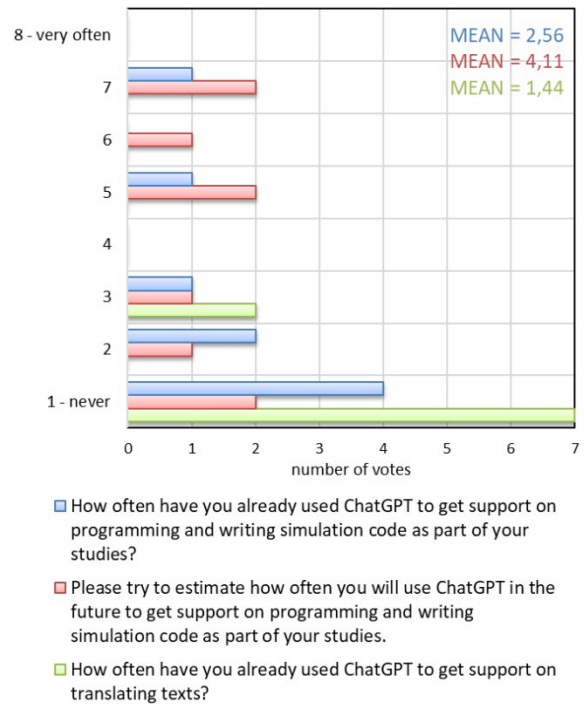


Fig. 4: Students' assessment of the frequency of use of ChatGPT for support in programming and creating simulation code as well as translating texts into and from foreign languages. The students were asked about the amount of their expected future use of ChatGPT for programming as well.

The situation is similar concerning the use of ChatGPT for translating texts, see the green bars in Fig. 4. However, on average, students assume that this will change, at least with regard to programming activities, see the red bars in Fig. 4.

Finally, we wanted to find out how well our approach was received by the students, see Fig. 5. How did the students rate our efforts to motivate them to familiarize themselves further with the new technology in the described way and to think about its possible future use? A significant majority was positively inclined towards our approach, see the blue bars in Fig. 5. For us, this is surprising in a positive sense. After all, the ChatCPT exercises meant additional work for the students. When asked whether their experience with ChatGPT during the semester had led them to use the technol-

ogy in general as part of their studies, the students gave a roughly neutral assessment on average, see the red bars in Fig. 5. The situation is similar with regard to general use outside of their studies, see the green data in Fig. 5.

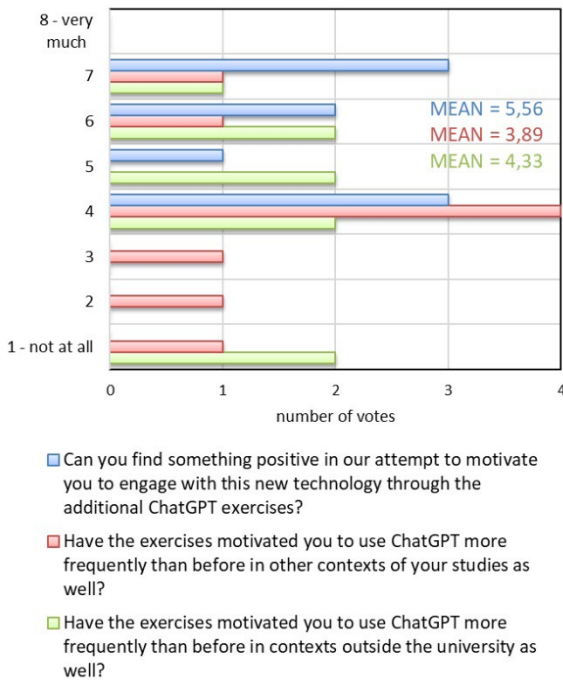


Fig. 5: Students' assessment of the impact of our attempt of involving ChatGPT exercises to encourage them to use the new technology more frequently. We differentiate between use in their study context and in a nonuniversity context. The average feedback on our attempt of motivating students to engage with ChatGPT was positive.

The spectrum is broadly distributed. Apparently, we were able to stimulate a significantly stronger engagement with the chatbot among individual students through our ChatGPT exercises. For others, this effect was only moderate. In a nonuniversity context, the use of ChatGPT increased slightly more than in the context of physics studies, at least among the few participants in this survey. This is shown by the comparison between green and red bars in Fig. 5.

4. Lessons learned

In summary, we investigated the extent to which the AI-supported chatbot ChatGPT can be used in physics studies in regular university

exercise classes in theoretical physics. Specifically, this attempt to integrate ChatGPT took place in the lecture-accompanying exercises on Theoretical Mechanics, a compulsory course in the third semester of the bachelor degree program in physics [2] at Otto von Guericke University Magdeburg. The time period corresponded to the lecture period of the winter semester 2023/2024. Accordingly, the students had free access to ChatGPT version GPT-3.5 [1]. They used the chatbot to work on additional exercises set for this purpose, both of calculation and conceptual, content-related nature. We did not encourage the students to register to use ChatGPT. Our aim was to motivate them to familiarize themselves with the new technology and to explore its capabilities, if necessary beyond the context of our exercises. At the same time, we wanted them to experience the opportunities it offers, but also the limitations that still exist. With the help of an online survey, we received feedback on the students' impressions.

Our test showed that ChatGPT version GPT-3.5 is capable of providing comprehensive and detailed explanations of physical phenomena and concepts. However, errors and inaccurate reasoning regularly occur when working on calculation tasks. This is reflected in the feedback from the students. On average, they found the use of ChatGPT to solve calculation problems not to be helpful, at least in the version that was freely available at the time of use. The opportunity to clarify content-related questions was rated much more positively.

In addition to these points, the online survey at the end of the semester showed that students used ChatGPT occasionally to frequently and would also consider using it in the future to clarify general physics content and questions. Interestingly, the willingness to use ChatGPT at least as an aid in writing scientific texts was low. Surprisingly, the students also gave little consideration to using ChatGPT for programming and creating simulation codes, or for translating texts.

For us, the findings from our study provide important hints for the future integration of AI-supported chatbots in university teaching. Based on the results, we see several approaches to further optimize and expand the

use of ChatGPT in physics studies. We should explain to students that ChatGPT can be a helpful tool for clarifying content-related and conceptual issues. In particular, we should convey to students that it is a very valuable tool when it comes to learning programming and creating individual program modules. It may not be enough to simply refer to the capabilities of ChatGPT. At the very least, students should be given a live demonstration of its use for creating program blocks or learning programming languages. The same applies to translating texts. ChatGPT is generally an excellent translation tool, which should be adequately communicated to students.

In addition, and surprisingly, we noticed a clear reluctance among students to use ChatGPT when writing lab reports, theses, or other academic texts. Above all, we see this as an indication that clearly formulated guidelines need to be established in academia in general, universities, and departments. These guidelines should be comprehensible and practicable for students, providing concrete examples. Above all, they must be clearly communicated and students must be actively made aware of them. It must be specified when AI-supported tools may and may not be used, how this is to be indicated, and how this is to be taken into account in evaluations and assessments. This would help students to take advantage of potential benefits without worrying about violating academic standards. It would also make it significantly easier for teachers to educate students how to use the tools. Students, and therefore our society, should not suffer any disadvantages in international competition as a result of limited experience with future standard tools, which could result from bans on their use.

In this context, it would be interesting to see in future studies whether students' attitudes towards the use of ChatGPT for writing lab reports, theses, or other academic texts change over the course of their studies. Simultaneous surveys involving students in different academic years could provide corresponding information. Such simultaneous data collection across different academic years over the course of the degree program could possibly reduce the influence of the rapid development of AI-supported tools on student feedback.

We would like to point out that the scope of possible applications will also grow with the further development of AI-supported chatbots. Since the first release of ChatGPT in version GPT-3.5 by OpenAI on November 30, 2022, there have been numerous innovations. These include optimized speech understanding and the recognition of images and videos since version GPT-4 [5]. Unlike the previous GPT-4, version GPT-4o, which is available at the time of writing this manuscript, is accessible free of charge. In this latest version, the chatbot can be connected to a number of plugins. In particular, the Wolfram Alpha plugin, for example, allows calculation exercises to be evaluated much more reliably. Here, arithmetic operations are passed to the Wolfram Alpha symbolic solver. For data protection and privacy reasons, we confined ourselves to working with a free version in our approach. We did not ask the students to register.

We assume that a repetition of the study in the future would already lead to different results due to the rapid development of the technology. The number of participants in our survey is relatively small. An increased number would certainly be helpful in future evaluations. In parallel to introducing measures to increase the number of participants, the investigation of other models could be considered in order to increase the informative value. Nevertheless, we believe that qualitative trends can be identified from the present survey and would like to thank the students for their participation. Their feedback provided us with valuable information for possible future designs.

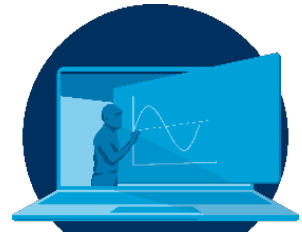
Ultimately, our study shows that ChatGPT can be a valuable tool in physics studies if used correctly. Continuous improvements and additions to the possible applications will significantly expand the potential of this technology in the future. We are convinced that teaching and learning processes can be significantly improved if used rationally in order to exploit the potential of the new technology. Our attempt shows that, on average, students rate it positively when they are introduced to the technology in the context of specific tasks.

Acknowledgements

A. M. Menzel thanks the Deutsche Forschungsgemeinschaft (German Research Foundation, DFG) for support through the Heisenberg Program, grant number ME 3571/4-1.

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Establishing student projects - About our approach in offering contacts outside of lectures and exercises

T. Schulze*, J. Weber, B. Beck, J. Weber

Chair of Fluid-Mechatronic Systems (Fluidtronics), Institute of Mechatronic Engineering, Faculty of Mechanical Science and Engineering, TU Dresden

Abstract

The decline in student numbers in mechanical engineering contradicts the existing shortage of skilled workers and the urgent need of the industry for qualified graduates. Particularly noticeable is the decreasing attendance in the courses of the Chair of Fluid-Mechatronic Systems at TU Dresden from 2015 to 2022. To counteract this trend and attract more students, three long-term application examples were developed as part of student projects: a hydraulic cargo bike, a low-pressure hydraulics demonstrator, and fluid technology components manufactured using 3D printing.

These projects have helped increase the attractiveness of the department by offering practical experiences that benefit both students and the industry. The students were able to deepen and apply their technical skills, develop project management and problem-solving abilities, and enhance their social skills such as teamwork, independent work, creativity, and innovation. Within these practical offerings, several student projects have already been completed, more students have been attracted to the field, and the public visibility of the department has been improved.

Der Rückgang der Studierendenzahlen im Maschinenwesen steht im Widerspruch zum bestehenden Fachkräftemangel und dem dringenden Bedarf der Industrie an qualifizierten Absolventinnen und Absolventen. Auffällig ist ebenso die geringe Präsenzteilnahme an den Lehrveranstaltungen. Um diesem Trend entgegenzuwirken und mehr Studierende zu gewinnen, wurden an der Professur für Fluid-Mechatronische Systemtechnik der TU Dresden im Rahmen von Studienarbeiten drei langfristig nutzbare Anwendungsbeispiele entwickelt: ein hydraulisches Lastenfahrzeug, ein Niederdruck-Hydraulik-Demonstrator und mittels 3D-Druck hergestellte Fluidtechnik-Komponenten.

Diese Projekte haben dazu beigetragen, mehr Studierende mit interessanten Studienarbeiten für die Fluidtechnik zu begeistern und durch erlebbare Anschauungsmaterialien die öffentliche Sichtbarkeit des Fachgebietes zu erhöhen. Die Studierenden konnten praxisnahe Erfahrungen sammeln, ihre fachlichen Kompetenzen vertiefen und anwenden, Projektmanagement- und Problemlösefähigkeiten entwickeln sowie ihre sozialen Kompetenzen wie Teamarbeit, eigenverantwortliches Arbeiten und Kreativität sowie Innovationsfähigkeit ausbauen.

*Corresponding author: Tobias.Schulze2@tu-dresden.de

This article was originally submitted in German.

1. Decline in student numbers

In the years up to 2021, a significant decline in student numbers can be observed in Germany and at *TU Dresden* in particular. Fig. 1 shows the trend for all subject groups up to the academic year 2023/2024. Across Germany, the number of students enrolled in the first semester of higher education has fallen slightly by 6% since 2015, from 506,580 to 481,469. In comparison, the decline at *TU Dresden* is almost twice as large at 11%: the number of students in their first semester of higher education fell from 5,514 in 2015/16 to 4,484 in 2021/22 and reached 4,881 in 2023/2024.

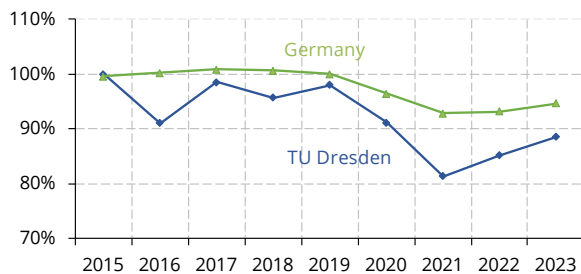


Fig. 1: Students in their first semester of higher education in Germany [1] and at *TU Dresden* [2] since 2015¹.

About one third of all students are enrolled in Engineering sciences (according to [3, 4], defined since 2015). In Germany in 2024, 27% of the first year students started in engineering sciences. The same year at *TU Dresden*, 35% of all students started within an engineering subject (electrical engineering and information technology, computer science, mechanical engineering, architecture, civil engineering, hydrosiences, transport engineering and business informatics) [2].

From 2015 to 2023, the number of first-year students in this subject group fell by 13% across Germany, while it fell by 30% at *TU Dresden*. This shows that interest in engineering at

TU Dresden is declining more sharply than the national average.

A detailed analysis of the individual faculties at *TU Dresden* in Fig. 2 shows different developments. At 63%, the *Faculty of Mechanical Engineering* recorded the sharpest decline in new students. At the *Faculty of Electrical Engineering and Information Technology*, there were 27% fewer new students, while the *Faculty of Computer Science* even recorded an increase of 29%.

These developments illustrate the need to take targeted measures to increase the attractiveness of *TU Dresden* and the *Faculty of Mechanical Engineering* in particular to attract more students.

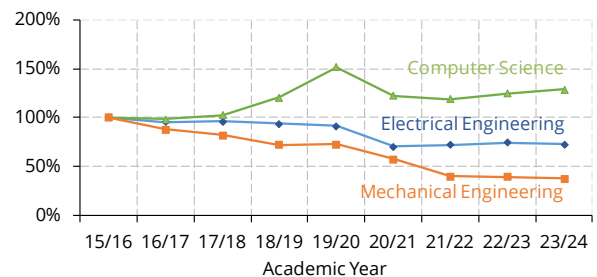


Fig. 2: First-year students at the Faculty of Engineering at *TU Dresden* since 2015/16 [2].

2. Developments and challenges at the chair

The *Chair of Fluid-Mechatronic Systems* offers courses in the main study program (semesters 5-9 of the diploma degree programs *Mechanical Engineering*, *Mechatronics* and *Teaching at Vocational Schools*) with different thematic focuses, which include both theoretical and practical phases. The largest course offered by the professorship is “*Fluid power components and system control*”. It comprises of 2 semester hours per week (SWS) of lectures and 1 SWS of tutorials. It is a compulsory module in the 5th

¹ Notes on the evaluation of the statistics:

- The federal statistics refer to the statistical year. Thus, for 2013, first-year students from summer 2013 and winter 2013/14 are counted. In contrast, the number of first-year students at *TU Dresden* is shown by academic year. In the academic year 2013/14 (shown here as 2013), first-year students from the winter semester 2013/14 and summer semester 2014 are counted including students on leave of absence. This difference evens out over time.

- The term “first-year students” refers to students who are starting from scratch. Students in their first semester are recorded as a further key figure. This also includes those who had already studied another subject before starting their new degree course. In engineering at the *TU Dresden*, this figure is approx. 50% higher than the number of “first-year students” starting their studies from scratch.

semester of the Diploma and Bachelor's degree courses in *Mechanical Engineering (General and Constructive Mechanical Engineering (AKM), Automotive and Rail Vehicle Engineering (KST))* and in the *teaching degree course at vocational schools (Production Engineering)*). As a result, students with different prior knowledge and interests take part, while at the same time a wide variety of academic topics are covered.

Despite its importance and breadth, there has been a clear decline in student numbers. Fig. 3 shows the trend of students enrolled in the course compared to the total number of newly enrolled students in mechanical engineering at *TU Dresden*. A relative decrease of 54% from 2015 to 2023 in the course correlates with the general trend at the *Faculty of Mechanical Engineering* of 61% from 2013 to 2021. This means that students who opted for the field of mechanical engineering at the start of their studies also took part in the course to the same extent. Possible reasons for this are:

- The *Fluid Engineering* specialization is only offered at two universities in Germany (*TU Dresden, RWTH Aachen*).
- The course is compulsory for *AKM* and *KST* students.
- Fluid technology is widely used in various industrial sectors such as aircraft and mobile hydraulics, sealing technology or control engineering.

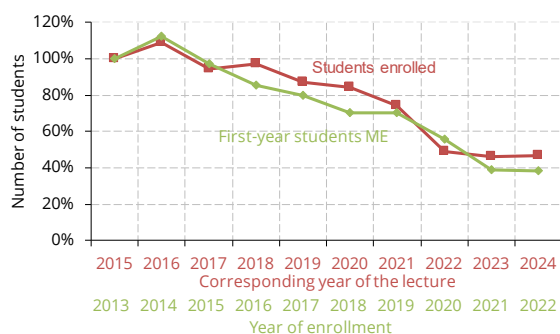


Fig. 3: Number of students enrolled at the TU Dresden Faculty of Mechanical Engineering (ME) and at the course "Fundamentals of Fluid Power Drives and Controls" in comparison (October of each year).

Fig. 4 shows the number of enrolled students compared to actual exam participation from the winter semester 2015/16 to the winter semester 2023/24. In addition to the decline in

student numbers already mentioned, the graph shows the comparison between total number of students enrolled on the course and number of students who participate in the final exam. What is striking is the increased decline in exam participation up to the winter semester 2021/22, where there is the greatest discrepancy between students registered for the course and those actually taking the exam.

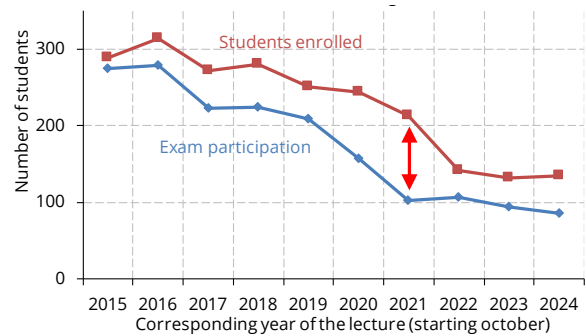


Fig. 4: Participation in the subject "Fundamentals of Fluid Power Drives and Control Systems" - enrolment vs. exam participation.

This dip could be due to various factors, which will be examined in more detail below. In order to halt the decline in student numbers and especially exam participation, various measures were developed and implemented at the professorship from spring 2022, e.g. the establishment of student working groups (WGs), which are described in chapter 3.

The initial results show that the proportion of exam participation from the winter semester 2022/23 is back at the original level of 2016/2017 and 2018/2019. This suggests that the measures taken appear to have been successful, although numerous other influencing factors could not be considered. For example, according to analyses by Hillebrecht [5], in addition to teaching quality, the quality of the study organization, (supra-)institutional aspects, socio-demographic characteristics or professional activity alongside studies can also influence the course of study and examination participation. According to Hillebrecht, however, further comprehensive observations and standardized measurement instruments are currently required to better understand their influence on academic success and to design future measures in a more targeted manner.

It is clear that – in addition to the number of students – the current situation and the background of the students currently in the main study program must also be taken into account. This also includes, for example, the effects of the coronavirus pandemic. The low attendance rate during the corona pandemic may have caused deficits in teaching and learning behavior as well as in contact between students and lecturers. The quantification of this influence based on the hybrid course "Fundamentals of fluid power drives and control systems" offered in winter semester 2021/22 shows that, according to Fig.4 , the greatest discrepancy between students enrolled in the course and those actually taking part in the exam has so far existed here. Fig. 5 shows the attendance at lectures and exams over the course of the semester, which was recorded manually for each lecture approx. 20 minutes after the start: Although 213 direct students were enrolled, only 131 attended the lecture at the beginning of the semester. In addition, there was a steady decrease over the course of the semester to around 50 students at the end of the semester. Interestingly, there were 154 registrations for the written exam (25.1.2022), but in the end only 103 (68%) actually took part (28.02.2022).

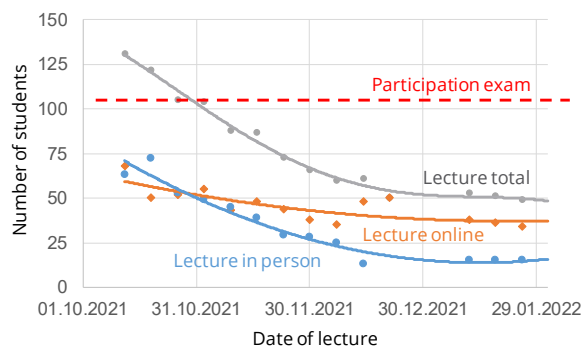


Fig. 5 : Participants in the subject "Fundamentals of Fluid Power Drives and Control Systems" (course and written exam) in winter semester 2021/22.

In the final internal teaching evaluation, possible reasons for the high withdrawal rate were discussed. As many students only decided not to take part a few days before the exam, they may not have felt sufficiently prepared. In addition, the intrinsic and extrinsic motivation of the students for the specific subject area of

fluid mechatronics could have decreased. In both cases, a causal influencing factor may be the loss of contact between teachers and students, which was particularly evident during the coronavirus pandemic.

In addition, these developments also have concrete consequences for the professorship: the falling student numbers are reflected, for example, in fewer applications for student research projects and SHK activities.

3. Countermeasures at the professorship - idea of the student working group

The Chair's experience to date shows that

- direct contact with students throughout the entire study period,
- opportunities for networking and mutual exchange as well as
- additional offerings beyond the traditional curriculum (e.g. excursions, guest lectures, conference participation)

are essential for arousing interest in the subject area, highlighting career prospects and, in particular, increasing motivation for active participation in courses.

In addition, scientific findings show that self-regulated learning (SRL) can significantly increase student motivation. Theoretical models emphasize the role of self-regulation in motivation and learning success. Empirical studies show that SRL improves performance and motivation by promoting autonomy and self-efficacy, and strengthens students' ability to set and achieve their goals. [6,7,8,9]

In order to transfer and apply these findings to teaching at the professorship, the following methods and associated sub-goals were identified:

- To create a collaborative learning environment for students by offering working groups (WGs) where they can support each other and work together on projects.
- To illustrate the relevance of what has been learned through practical, realistic application examples and to arouse/increase students' curiosity and general interest in the subject area.

- Using self-regulated learning through experimentation to provide students with more opportunities to test theoretical concepts practically/actively and explore them independently, which promotes their motivation and understanding.

In summary, the combination of self-regulated learning, practical application examples and networking in student working groups can significantly increase student motivation and understanding. These approaches not only promote autonomy and self-efficacy, but also prepare students better for applying the lecture content and taking the exams during the semester. Examples such as the existing university groups *Akaflieg*, *TURAG* and *Elbflorace* at *TU Dresden* show that such concepts can be successfully implemented and promote the link between studies, research and industry.

Thanks to funding from the *Faculty of Mechanical Engineering* as part of teaching/learning projects, the professorship was able to launch a project in June 2022 that addresses the challenges outlined above with regard to the declining number and participation of students at the *Chair of Fluid-Mechatronic Systems Engineering*.

The primary aim of the project was to improve teaching and to increase general interest and curiosity in the subject area through practical application examples. The aim was to reduce the withdrawal rate from examinations and motivate a higher proportion of enrolled students to actively participate in courses offered by the professorship. In addition, student exchange ("help for self-help") and contact with lecturers should be promoted to receive direct feedback on the quality of teaching.

In the long term, the project should halt or counteract the decline in student numbers. This will be achieved by continuously improving our didactic teaching methods ("making teaching more attractive") and by establishing cross-semester-spanning student research projects and assignments. Demonstrators will be developed together with students that can be used as 'tangible fluid technology' to increase the visibility of mechanical engineering, particularly fluid mechatronics. They can be used during lectures and tutorials in all of the professorship's courses as well as in a general

social and school context, for example in school projects or presentations on campus and at public events such as the *Dresden Science Night*.

A central component of the project was the preparation of a student working group consisting of a core team of 4-12 students who are responsible for the conception, development and implementation of various projects within the group. They are supported by one or two research assistants. The aim was to develop application-oriented, comprehensible demonstrators that make fluid technology topics "tangible" in practice.

So far, three application examples have been tested as part of the project, which are explained in detail in the following chapters:

1. A **cargo bike** with a hydrostatic drive instead of a chain drive,
2. a demonstrator for **low-pressure hydraulics** in the 0 to 50 bar range and
3. the evaluation of **3D printing** as a manufacturing method for fluid technology components in the low-pressure range.

4. Application example "cargo bike"

The concept of the *cargo bike working group* is based on the "National Fluid Power Vehicle Challenge" in the USA [10], in which student working groups equip bicycles with hydrostatic drives within a semester and test them in various disciplines. Fig. 6 shows two winners from the 2017/18 season.

In contrast to the USA, where the teams change after each semester and development begins anew, the professorship's *cargo bike* working group pursues the goal of building a functional demonstrator within one semester and continuously developing and optimizing it across semesters.

The concept of the working group provides for a multi-stage structure: A core team of students from various fields of study and specializations from the entire range of courses offered by the professorship (see *chapter 2, p.2*) is largely responsible for the conception, development and implementation of the project. Within the working group, it is possible to complete activities either individually or in groups.

In addition, well-defined detailed questions can be worked on separately - e.g. as part of student research projects or final theses.

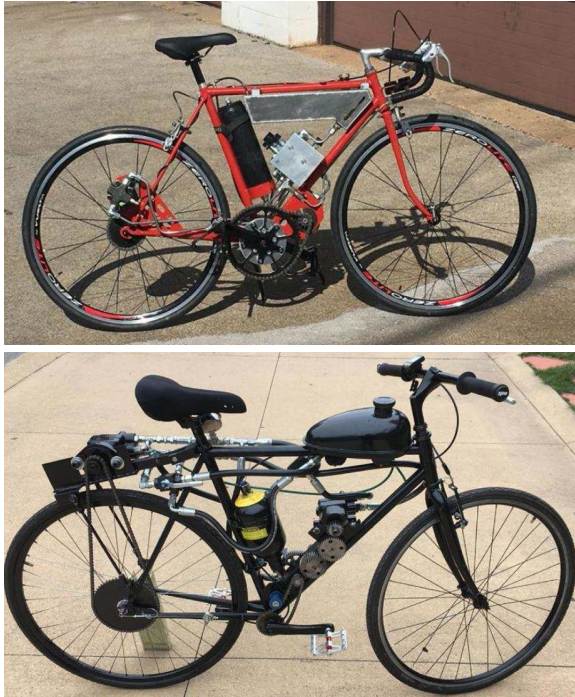


Fig. 6: Hydraulic bicycle at Cleveland State University (top) and the Milwaukee School of Engineering (bottom) [10].

In terms of technical aspects and development priorities, hydraulic transmissions enable traction-free, stepless gear ratios as well as flexible power transmission and energy storage.

The knowledge about the properties of hydraulic transmissions, their design and dimensioning, imparted in the lectures and exercises, can be put into practice with this application example. In addition, further development focuses on both mechanical engineering and fluid technology in particular, such as

- concept development,
- modeling and simulation,
- system design and
- experimental tests and optimization.

In addition to the technical aspects, the working group also promotes non-technical (social and interdisciplinary) skills such as teamwork, project management, communication and presentation skills as well as sales activities. Among other things, the concept of the AG provides for

- experiences and results are presented to other members of the working group as well as the professorship at fixed intervals and
- the demonstrator is supervised and presented by students at public events such as laboratory tours or the *Dresden Science Night*.

In addition, a versatile use is conceivable, e.g.

- as a rental bike for transportation and errands in the campus catchment area,
- as a basis for discussing new technologies and business areas with sponsors and industrial partners or
- as an example of use in lectures, exercises and teaching practicals for the practical explanation of lecture content.

For the integration of hydraulic transmission, the use of a cargo bike was identified as a technologically more promising basis in comparison to the use of weight-optimized everyday bikes with mature mechanical power transmission.

The aim of the working group's previous work was to design and dimension drive concepts and to investigate them on the basis of simulations. As a result of the design development process according to VDI 2221, a hydraulic 7-speed gearbox consisting of a toothed ring pump and three independently engageable orbital motors as well as a basic concept for a hybrid drive with hydraulic accumulator were developed. Both systems were set up and investigated as a 1D system simulation model.

As a result of the work, a system variant is now available as a rough design. For further development, suitable motors and pumps must be developed that function at very low speeds and high torques and can also be integrated into the cargo bike.

The project idea was well received in the industry. The company CUBE [11] provided a frame for the cargo bike, which forms the basis for the work that has been carried out and will be carried out in the future with regard to the installation of the hydraulic drive (Fig.7)

Despite intensive advertising measures, however, not enough students were found to set up a working group. Only two student research projects focusing on *hydraulic cargo bikes* have

been completed so far to achieve the development results described above. Several factors could explain the low level of participation: The complete conversion was perceived as too difficult, which deterred potential interested parties.



Fig. 7: The chair's cargo bike as the basis for installing the hydraulic drive.

In addition, a hydraulic bike does not initially offer any significant advantages over e-bikes due to its principle, i.e. without specific optimization of the drive technology. Our hope that the enthusiasm for hydraulics would compensate for this disadvantage was not fulfilled. In addition, due to the low number of students overall, there were only a few interested parties, as other projects such as 3D printing or low-pressure hydraulics were more attractive.

5. "Low-pressure hydraulics" application example

Similar to the concept of the hydraulic cargo bike, the design and control of large industrial hydraulic systems can be reproduced on a small scale and further developed independently in the *low-pressure hydraulics* application example. The aim of the example project was to develop a demonstrator that can be operated independently in the low-pressure range using simple hydraulic circuits and controls based on single-board computers (e.g. Raspberry PI) or microcontrollers (e.g. Arduino or ESP32).

The advantage of self-sufficient systems designed in this way is that they can be easily scaled in terms of their complexity and difficulty and can therefore be adapted to different levels of knowledge.

For example, simple circuits can be used for student research projects and internships or more complex systems for dissertations. At the same time, the interaction between different domains such as mechanical structure, hydraulic system and electrical control can be clearly illustrated. In the specific example, this means that the mass can be moved using gesture control. This makes it possible to visually and acoustically experience how the motor rotates with the pump and how the cylinder moves.

The basic technology required for the construction could be procured from funds for teaching/learning projects of the *Faculty of Mechanical Engineering*, which underlines the importance of financial support for such projects. To date, five student projects have already worked on a closed hydraulic compact drive (Fig. 8). The group was able to work on a common topic, while each student was given an individual sub-task. For example, the drive system for the low-pressure hydraulic system was developed jointly, with one student developing the hydraulic structure and another the control system.

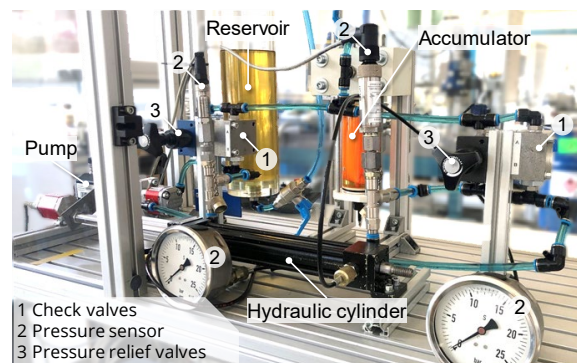


Fig. 8: Demonstrator of a closed hydraulic compact drive.

The developed hydraulic compact drive was presented by students of the working group at the *Dresden Science Night* and could also be tried out by the guests themselves. The feedback was very positive. This increased interest in and understanding of fluid power drives among both target groups.

6. Application example "3D printing"

Current industrial applications already use components manufactured using 3D printing,

as these are lighter, more compact and more energy-efficient than traditionally manufactured components [12]. As a modern manufacturing technology, 3D printing offers students another interesting field of technology within fluid power: through cost-efficient prototyping, for example of complex valve or channel geometries, and rapid iteration, they can gain practical experience and deepen their knowledge of the fundamentals of fluid technology and the functioning of hydraulic components.

In a total of three student research projects to date, the students have used the 3D printer procured with funds from the *Faculty of Mechanical Engineering* for teaching/learning projects to produce various hydraulic components from industrial applications. They then examined these regarding the suitability, possible applications and limits of the new production technology under special fluid technology aspects such as tightness or pressure resistance (Fig. 9). After a technical briefing, the students were able to work independently and implement their own ideas.

The application of a modern and innovative manufacturing technology in conjunction with the independent execution of experiments and testing of various (own) designs was rated as very positive and motivating by the students. In addition, the developed components can be used as demonstrators in teaching or at public events to illustrate fluid technology.

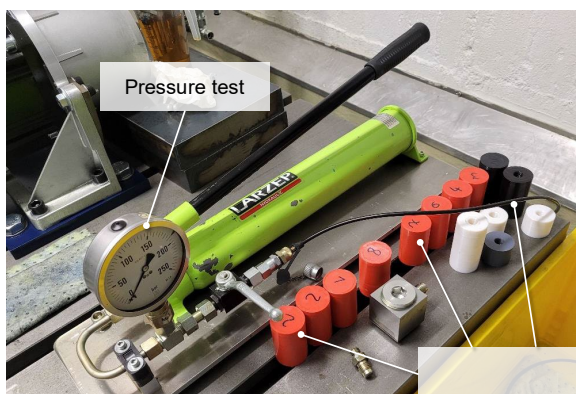


Fig. 9: Pressure test for additively manufactured test specimens with different pressure settings and materials.

7. Conclusion

The *TU Dresden*, in particular the *Faculty of Mechanical Engineering*, has been confronted with

a significant decline in student numbers in recent years. In addition, there are high withdrawal rates for examinations, as observed at the *Chair of Fluid-Mechatronic Systems Engineering*. These developments have negative consequences, such as a lack of support in research and teaching.

Consequently, there is an urgent need for action to counteract this trend and increase the attractiveness of *Fluid Power Technology*. This includes the introduction of practice-oriented teaching methods, the promotion of self-regulated learning through student working groups and increasing the visibility of the subject area. The transfer of industrial application examples into a comprehensible and manageable size is a useful building block on this path. Ideally, this should be done by the students themselves, but – as the experiences from the projects presented shows – it requires a considerable amount of support from academic staff. The example of the *cargo bike* working group, which was not accepted by the students as expected, illustrates the need for further analysis and adjustments in order to achieve positive effects in the long term.

Nevertheless, initial successes are visible, particularly in the application examples of *3D printing* and *low-pressure hydraulics*. These projects show how innovative approaches can be implemented in teaching to increase student interest and motivation. For example, the presentation of the low-pressure hydraulics demonstrator at the *Dresden Science Night* aroused widespread interest, and the positive feedback speaks for its success. A total of ten student research projects were completed in 2023 and 2024 as part of the example projects presented. With a total of around 25 student research projects at the professorship each year, this is a good result. In addition, further company contacts have been established to support the projects.

The next steps include further topics for student research projects, the derivation of specific exercise and lecture content and the further development of the demonstrators.

Acknowledgements

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Literature

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Conception of an experimental laboratory for the digital and flexible design of research-oriented teaching

Lisa Eggerichs, Hans Jörg Schmidt

Center for Interdisciplinary Learning and Teaching, TU Dresden, 01062 Dresden

Abstract

The experimental laboratory for the digitalization and flexibilization of teaching at TU Dresden is an interactive, flexibly configurable space consisting of various physical and virtual components. Lecturers receive support in the development and implementation of (partially) digital courses with a focus on research-oriented teaching and learning formats. Didactic concepts, such as flipped classroom or blended learning approaches, can be tested in the experimental laboratory, and media for use in research-oriented teaching can be produced easily e.g. by using a lightboard

The article presents the concept of the experimental laboratory as a teaching learning laboratory and relational space, discusses relevant theoretical constructs and derives scenarios for the use of the space and elements of implementation. Finally, the current state of implementation is described.

Das Experimentallabor für Digitalisierung und Flexibilisierung von Lehre an der TU Dresden ist ein interaktiver, flexibel gestaltbarer Raum, bestehend aus verschiedenen physischen und virtuellen Komponenten. Lehrende erhalten dort Unterstützung bei der Entwicklung und Durchführung von (teil-) digitalen Lehrveranstaltungen mit einem Schwerpunkt auf forschungsorientierten Lehr- und Lernformaten. Didaktische Konzepte, wie z. B. Flipped Classroom oder Blended Learning-Ansätze, können im Experimentallabor hands on ausprobiert, Medien für den Einsatz in der forschungsorientierten Lehre – u. a. mit Hilfe eines Lightboards – niedrigschwellig produziert werden.

Der Beitrag stellt das Konzept des Experimentallabors als Lernwerkstatt und relationaler Raum vor, geht dabei auf relevante Theoriekonstrukte ein und leitet daraus Raumnutzungsszenarien und Elemente der Realisierung ab. Schließlich wird der aktuelle Umsetzungsstand beschrieben.

*Corresponding author: lisa.eggerichs@tu-dresden.de

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1. Introduction

'Work 4.0', 'Industry 4.0' or 'Administration 4.0' are terms that allude to current processes of change in society driven by digitalization. The massive change in fundamental areas of society signaled by these terms also has an impact on university learning and teaching and thus also on the associated forms of work and teaching. Analogous to the aforementioned terms, 'University 4.0' or 'Learning 4.0' has therefore been mentioned more frequently in recent discussions on higher education policy and didactics.

In addition to the digitalization of all areas of society and the associated changes in work, communication and collaboration processes, a change "from teaching to learning" [1, 2] has also been postulated for some time in the field of higher education, which - similar to the 'New Work' movement in the context of 'Work 4.0' - entails a development towards project-oriented, interdisciplinary and problem-based learning in group or project work [2]. The catchphrase "from teaching to learning" expresses renunciation from input control towards an orientation in direction of the results or products of learning (output orientation) and the skills and strategies that are used or required to achieve these goals [3].

Digital media and communication contexts can actively support this shift, as they change the view of teaching-learning processes [4]. In addition to a didactically meaningful digitalization of learning and teaching, the physical infrastructure at universities also needs to be redesigned in order to take the changing requirements and adequate spaces for realistic 'Learning 4.0' in the 'University 4.0' into account.

The experimental laboratory considers these aspects and opens up an interactive exploration space for (partially) digital teaching, in which researchers from DRESDEN-concept institutes and lecturers at TU Dresden can receive support in the design of digital and hybrid research-oriented courses and get assistance in the didactically meaningful use of digital media and learning materials.

It is part of the Teaching Synergies Program and contributes to the development and testing of innovative (partially) digital teaching and learning scenarios in the context of the University of Excellence *TUD 2028 - Synergy and beyond* [5]. It provides users with impetus and opens up exchange opportunities for the new and further development of innovative teaching and learning offers in the context of flipped classroom or blended learning concepts in general.

The opportunity to try out different spatial-media-didactic settings makes it possible to experience and make experienceable a wide range of design options and usage scenarios for teaching and learning locations at TU Dresden and their higher education didactic justification in direct interaction.

The experimental laboratory does not only offer a physical space for video production with a lightboard, but also two rooms for testing face-to-face learning spaces in the context of blended learning. Conceptually, it goes beyond a static room set-up. It is to be understood as a space in the broader sense, in which lecturers can develop, test and exchange (partially) digital and hybrid learning arrangements in a guided and/or free experimental manner. The focus is particularly on testing hybrid and digital implementations of research-oriented teaching. Conceptually, it is based on the idea of *teaching learning laboratory in higher education (German: (Hochschul-)Lernwerkstatt)* in connection with a *relational understanding of space* according to Löw [6].

Based on a close relation between research and teaching, the experimental laboratory addresses the following question:

Which digitalization and flexibilization options support in particular the linking of research and teaching?

In this context, offers in the experimental laboratory provide answers to numerous questions relevant to higher education and media didactics:

- How can interactive learning settings being oriented towards blended learning approaches be implemented in physical and digital space?

- Which teaching-supporting digitalization and flexibilization options can be used in particular to address the respective subject-specific form of research in teaching?
- Which digitalization and flexibilization options can be used in particular to support research activities or the understanding of research processes?
- Which digitalization and flexibilization options can be used in particular to implement the basic pillars of research-based learning [7] in teaching?
- How can the room design and use of space in face-to-face and hybrid settings be particularly well combined together linking teaching and research?
- What teaching-supporting presentation and digitalization options does the respective form of research offer?
- Which analog/digital media can be used to support the research activity or the understanding of the research process?
- How do the range of materials, media, furnishings and equipment effect the use of the room?

Subsequently, relevant theoretical concepts from the areas of learning space design, teaching learning laboratories in higher, relational understanding of space, research-oriented learning and teaching and the use of digital media in university teaching are presented before the components of the concept are explained in more detail.

2. Presentation of relevant theoretical concepts

Various relevant theoretical concepts emerge from the considerations. For example, the concept and design of the experimental laboratory includes educational theory principles on learning and research, media didactic considerations and concepts for research-oriented teaching/learning formats. The conceptual and physical design of the space is based on considerations of spatial sociology, learning space development and teaching learning laboratories in higher education (German: Lernwerkstatt).

The aforementioned change of perspective from teaching to learning goes hand in hand with a critical reflection on the relationship between science and society or profession and society [3]. Education at a college or university takes place in the "medium of science" [3, 8] in the sense of this cognitive strand. Following Wilhelm von Humboldt [9], science is understood as a problem that has not yet been fully resolved, which rather requires active learning via a 'deep approach' - and consequently implies learning that is oriented towards problem solving competence and self-organization [3]. Research refers to the same driving force as learning and strives to generate new knowledge [10]. Research-based learning (according to Healy & Jenkins [11]) is a macro method and at the same time an implementation of research-based [12] or research-oriented learning and teaching [13]. Depending on the degree of active involvement of students and the way in which research is addressed (content or process), a distinction is made between research-tutored, research-led and research-oriented learning [11] (in addition to the above-mentioned research-based learning).

Research-based learning as a macro method is a university didactic format in which students conduct their own research in seminars and projects. Learning and research are combined through the provision of learning arrangements. Ideally, research-based learning takes place in a successive research cycle and usually begins with the identification of topics or the formulation of questions or hypotheses, continues with the implementation and evaluation of the results and ends (always maintaining its open-ended character) with the scientific communication or application of the results.

In order to design the research cycle in a subject-specific way and to support it digitally, it is helpful to deal with research and science in general and to take different disciplinary cultures into account. The German Science and Humanities Council [14] identified six distinct forms of research: the experimental form of research, simulation, the observational form of research, the hermeneutic-interpretative form of research, the formative form of research and the conceptual-theoretical form of

research. Subsequently, Reinmann [15] formulates concrete cognitive activities such as qualitative or quantitative data collection, design or experimentation.

Research-based learning is procedurally based on five pillars: project management, feedback structures, reflection, documentation and presentation [7].

Based on various approaches [11, 12, 16] in the field of research-oriented teaching, which relate to the core idea of education through science, the three University of Excellence programs developed a common understanding to strengthen research-oriented teaching at the Dresden University of Technology. The aim of this TUD-specific understanding, which is referred to as "research-oriented learning and teaching (in German: Forschungsorientiertes Lernen und Lehren, FoLL)", is to develop research skills (in accordance with the European Competence Framework for Researchers [17] adopted in 2023) and to promote a research-oriented attitude. This involves combining research as content, research as a path forward and reflection on these activities as knowledge. Thus, students should be enabled to learn to conduct research and to educate themselves through the self-efficient practice of science, as well as to acquire relevant research skills, become familiar with research content and critically reflect on the chosen approach in order to gain knowledge, either as part of courses or in the course of their own research projects.

Based on that, asking about the potential of digital media, it has to be considered, what opportunities digitalization offers for the respective form of research or the cognitive activities assigned to it. The question then arises as to what "potential digital media offer as teaching and learning tools or in the form of learning and educational spaces for research activities in the context of specific events or on one's own responsibility" (original: "Potenziale digitale Medien als Lehr-Lernwerkzeuge oder in Gestalt von Lern- und Bildungsräumen für Forschungstätigkeiten im Rahmen von konkreten Veranstaltungen oder in Eigenverantwortung bieten") [18, p. 72]. This leads to three further questions:

- At what point in time can digital media be usefully employed (→ when)?

- Which digital media or processes are suitable for the specific situation (→ what)?
- How and with which digital media can the respective pillar be addressed (→ how)?

In this context, digital media are understood as tools to support research-oriented teaching [18].

In order to answer the aforementioned content-related questions in the respective context of specific courses, the experimental laboratory is to be set up conceptually as a teaching learning laboratory (German: Lernwerkstatt) and, based on their actual demand, offers lecturers the opportunity to explore the topics associated with teaching implementation and to work on them successfully for their research-oriented teaching.

This approach being focused on implementation follows the trend that teaching learning laboratories have become in recent decades an innovative way of training future teachers in didactic and pedagogical subject areas by providing them with a curated space for action and experience [19]. Historically, teaching learning laboratories in higher education are more likely to be found in the field of teacher's training and the didactic design of learning spaces at elementary school and nursery school but are also increasingly being used at universities and colleges to develop students' capabilities. However, this idea of teaching learning laboratories can now be adapted not only to teacher's training and the development of students' competencies, but also to the qualification of university lecturers. Through the principle of the didactic double decker (= learning on two levels, which includes both subject-specific and social/emotional aspects) being inherent in the learning workshops, the teachers of a university are understood as learners in teacher's training and the pupils as students.

As a basis for the conceptual considerations, it is helpful to use the German term *Lernwerkstatt* and break down the term 'Lern-Werk-Statt' into its basic meaning units and to assign specific meanings to each of the three single word components. For example, learning (lernen, hier: LERN) in a 'LERNwerkstatt' refers to an innovative concept of learning as "self-

learning construction" [19, 20]. The focus is shifted to the explorative learning (and away from instructional teaching) of learning content [21]. The meaning of the term WERK in sense of an artifact, output or piece in the German term 'LernWERKstatt' refers more to a product being created through explorative learning and self-directed learning. However, the work is rarely clearly defined and can also be seen as an abstract construct in the sense of changing/improving an initial situation or in the development of declarative and procedural knowledge. The element 'STATT' in the term 'LernwerkSTATT' refers to the physical (digital, hybrid) space [22] as a lab or studio [23] and thus describes a high-quality equipped physical space [24].

Teaching learning laboratories can be understood as an environment that encourages activity, i.e. provides impetus for active interaction with people and objects. This way, they provide the basis for learning through research and discovery [25, 26].

In order to align the experimental laboratory with the target group of university lecturers as learners, it also seems sensible to focus on their learning in the context of a space (or more specifically: a teaching learning laboratory). The focus here is particularly on the subjectivizing learning path and in the transactional relationship of the teachers (= learners) to the physical space as a three-dimensional condition and to the objects in the space. Beyond the space being equipped in a certain way, university workshops also become other spaces that emerge through the interrelation of learners, things, spatial structures and learning content [6, 27].

Thus, it makes sense to look at the space of the experimental laboratory and the processes taking place in it in terms of a relational understanding of space and thus to understand social construction as an additional space-forming momentum. In this way, the processual emergence of space is conceptually taken into account [28]. Accordingly, spaces do not simply exist as a material condition, but are also produced and constructed through social action [28]. Vice versa, spaces in turn influence the actions of the people who use them.

Consequently, space becomes a "hybrid of material conditions and social use" [29], i.e. a mix-

ture of objects of the elements *social goods* and *living beings*, which are perceived by the acting persons and combined to form a space [29].

Social goods are the non-human elements in a space, which in turn can be divided into primarily material goods (e.g. furniture) and primarily symbolic goods (e.g. signs). Living beings, i.e. people and animals, are therefore also elements of space. The process of *spacing* (i.e. the targeted preparation of a space) involves placing and situating the elements, whereby the *synthesis achievement* is shown in the merging of these into a coherent perceptual space [30]. From a spatial sociological perspective, the "process of spacing [...] comprises the placement of social, primarily material goods and people (or other living beings)" (original: „Vorgang des Spacings [...] das Platzieren von sozialen, primär materiellen Gütern und Menschen (bzw. anderen Lebewesen)“) [6, p. 158]. It includes processes such as the erection, construction and positioning of elements [6]. The synthesis achievement consists in "combining social goods, people, groups of people, plants and/or animals into spaces via processes of perception, imagination and memory" (original: „Zusammenfassen von sozialen Gütern, Menschen, Menschengruppen, Pflanzen und/oder Tieren zu Räumen über Wahrnehmungs-, Vorstellungs- und Erinnerungsprozesse“) [6, p. 159].

Against the background of being able to describe processes in spaces with the help of the relational understanding of space and thus also to focus on the learners, the experimental laboratory should be set up according to the elements it contains (spacing) and the creation of relationships between these elements (synthesis).

In order to create a teaching/learning offer that enables learners to make their own learning experiences on the one hand and to transfer these to the students as learners on the other, it is necessary to take a comparative look at different learning space realizations and principles of learning space design. From this systematic comparison, conclusions can be drawn for the establishment of a space that is appropriate to the qualification objectives. It is important that the space unobtrusively invites users to experience higher education di-

dactic inspiration and to accept opportunities for exchange that promote the new or further development of innovative teaching and learning opportunities in the context of the flipped classroom or in the context of blended learning concepts in general.

In addition to the derivations from the aforementioned concepts, considerations and conclusions of the Stifterverband on the topic of learning space design are also included in the implementation. Based on expertise in higher education, media and spatial didactics, the association formulated ten guidelines for future-oriented learning space design in 2022. Among others, the following characteristics are formulated for the design of learning spaces: Learning spaces should be adjusted towards active learning settings, allow autonomy for learners and offer universities a variety of different types of learning spaces. Furthermore, spaces for hybrid teaching/learning settings are required [31].

However, In addition to the implementation of digital spaces with the help of digital media, , physical space is also to be taken into account in modern university teaching, as the physical space represents space of perception of digitally inscribed central context of experience in learning, which should also be taken into account when learning with or via digital media [2]. Conceptually, for the experimental laboratory this means "developing hybrid teaching and learning space constellations" (original: „hybride Lehr- und Lernraumkonstellationen zu entwickeln“) [32, p. 301] and making the experience gained there usable for the context of research-oriented learning and teaching.

The experimental laboratory thus offers the opportunity to test digital media in a physical space context, to develop implementations for hybrid learning spaces and to reflect on the use of digital media.

As the experimental laboratory focuses in particular on the use and production of digital or partially digitalized teaching/learning content in the context of research-oriented learning and teaching, the media perspective is to be taken into account. Digital media are considered in the experimental laboratory in the tradition of 'technology-enhanced teaching', whereas digital media are understood "as a

component of a complex teaching-learning arrangement, which is characterized by the totality of different (digital and analogue) offers " (original: „als Bestandteil eines komplexen Lehr-Lernarrangements, welches durch die Gesamtheit unterschiedlicher (digitaler und analoger) Angebote [...] gekennzeichnet ist“) [4, p. 1042]. The experimental laboratory takes up this consideration and therefore always addresses the didactic embedding of digital media in a broader overall setting.

In the following section, conclusions will be drawn from the conceptual considerations and the equipment (spacing) of the room will be specified.

3. Implementation of the concepts in the experimental laboratory

In order to progress from conception to concrete implementation, the experimental laboratory addresses both teachers as learners and students in accordance with a didactic double-decker.

As a result of the design of the experimental laboratory as a teaching learning laboratory in higher education the learners and the associated "product" in the sense of a (learning) result are taken into account on the one hand, derived from the supporting sensory units of the 'LERN-WERK-STATT', and on the other hand a physical place with additional digital elements is set up, which stimulates an active construction performance and is characterized by a relational understanding of space.

This enables teachers (= learners) to tackle with content independently and to build up new knowledge themselves.

The sense unit 'STATT', which relates to the physical learning location, is extended by a relational understanding of space and set up in such a way that both the processes of spacing and synthesis are supported.

Based on the consideration that the laboratory space actively contributes to learning through spacing and synthesis and that learning processes can be initiated as a result, various requirements can be derived for the physical space.

On the one hand, flexible social goods (i.e. non-

human elements or objects) such as flexible furniture, mobile walls, blackboards etc. have to make it possible to design the room in a way that is appropriate to the learning objectives without big additional effort. The items selected for this purpose should also enable a variety of teaching and learning situations in order to create spatially, socially and didactically appropriate arrangements (e.g. for group or individual work).

Following the guidelines of the Stifterverband, the flexible furniture is supplemented by hybrid-capable equipment. With regard to the furnishings (elements of spacing), a distinction can be made between *materials/media* and *furnishings/equipment* in order to systematize the approach.

The range of materials and media within the experimental laboratory room is made available in analogue form and digitally via a cloud. Texts and other media, such as videos, are offered on the following topics: Instructions for using digital media, texts and advice for incorporating digital media into university teaching, texts on learning space development (regarding didactic conception as well as spacing), on supporting learning processes as well as on research-related teaching.

Thus, the experimental laboratory provides a variety of digital media and options for media production that may be relevant for use in teaching. The centerpiece is the lightboard (95 inches), which enables the interactive design and recording of digital course materials in a special way and creates a direct visual link between research content and the researcher.

In addition to the non-human elements, the social use by people is also relevant for the constitution of a space, following Löw [6]. In this understanding, the teachers become elements in the space that the respective individual incorporates into their perception and thus constructs a relational space. In order to initiate social use, *workshops*, *exchange* and *networking formats* and *accompanied opening hours* are offered.

As part of the experimental laboratory, e.g. workshops on the lightboard and the use of lightboard videos as teaching/learning videos or explanatory videos (with associated OPAL self-study course including accompanied video

shooting) can be offered, , or workshops on the topic of "research-oriented learning and teaching with the help of digital media" can take place.

The experimental laboratory is open at certain times being attended by student assistants. During these opening hours, it is possible to work independently with both the materials and the media, prepare teaching and learning materials or enter into an exchange with other lecturers. In this respect, the experimental laboratory also functions as an *open space* that can be accessed both digitally and in the room itself. Here, for example, experiences in teaching can be reflected upon or best practice examples can be presented, collected and exchanged.

It is also possible for researchers from the DRESDEN-concept institutes and lecturers from TU Dresden to work in tandem to design smaller research-oriented courses in the rooms of the experimental laboratory and have them evaluated at the same time.

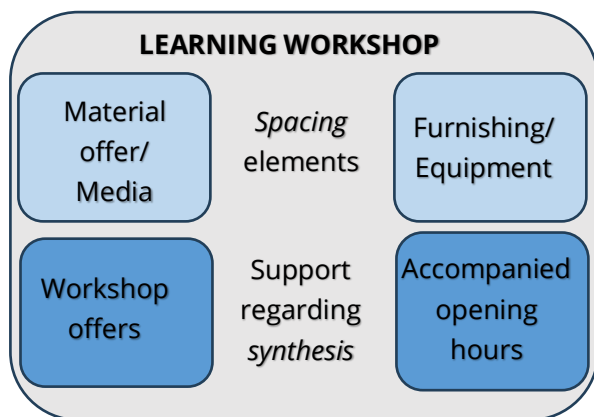


Figure 1 : Schematic representation of the concept and its components

Based on the conceptual considerations made so far and the conclusions drawn from them regarding the furnishing and use of the experimental laboratory, various room usage scenarios can be derived.

4. Room utilization scenarios for the experimental laboratory

The experimental laboratory is set up for different usage scenarios and should therefore allow for the most versatile use possible.

Teachers here have (1) the opportunity to develop innovative teaching/learning concepts by working independently with the available materials. In addition, teachers can (2) experiment with the variable furnishing of the room and its spacing and (3) exchange ideas about the materials and concepts they have developed in order to test their own settings (e.g. blended learning concepts) and exchange ideas with higher education didactics experts or other lecturers.

However, the experimental laboratory can (4) also be used as a higher education didactic teaching and learning location and thus for regular teaching and/or for special learning and study projects. An application procedure can be implemented here, within which interested lecturers submit a utilization concept, discuss it with university didactics experts, reflect on it and then evaluate it.

The experimental laboratory (5) can be booked as a learning space at certain times (by both lecturers and students). In this context, the room is then used as a university learning space for project and problem-based teaching and learning by students and project groups. The room (6) can also serve as a location for formats such as hackathons in the field of digital/hybrid teaching and accommodate research-oriented teaching projects.

In addition to the scenarios mentioned above, the experimental laboratory will also (7) be available as a didactic teaching, learning and advisory space. In this context, TUD's Center for Interdisciplinary Learning and Teaching will be responsible for further training, workshops and consultations on blended learning concepts and university and media didactics (including tool training), which complement the thematic focus of research-oriented learning and teaching.

In the future (8), the experimental laboratory will also be accessible as a networking space for university-wide communities of practice and learning communities.

5. Current status of implementation and outlook

The technical setting currently consists mainly of the lightboard, which interested lecturers can use to film explanatory videos. There are

also various microphones and wireless headsets, a 360° camera and a document camera. The asynchronous support offer consists of a self-study course on the learning platform OPAL, which covers the theoretical basics of creating teaching/learning videos and coordinates the scheduling of the accompanied production.

A spatial change and expansion of the experimental laboratory and the technology it contains is planned. By separating the lightboard and technology room from the other room components, disruption-free video production can be guaranteed in the future. The range of materials and the flexible and innovative furnishings will then be located in two additional rooms.

In completion to the spatial changes, the equipment will also be expanded to include additional digital media, which will particularly support the linking of teaching and research, as well as the interweaving of synchronous and asynchronous teaching.

The next step is to establish workshops on topics such as blended learning or research-oriented learning and teaching and to work with users to develop offers for learning space design and the didactically appropriate integration of teaching/learning videos into their didactic scenarios.

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Term paper on the design and construction of a gear shaft

T. Rosenlöcher, B. Schlecht

Chair of Machine Elements, Institute for Machine Elements and Machine Design, Faculty of Mechanical Engineering, Dresden University of Technology

Abstract

In the subject of Machine Elements, the teaching content covered in lectures, exercises, and calculation tutorials are supplemented by a term paper to be completed over the course of the semester, in which the knowledge gained on the design and construction of machine elements is to be applied independently to the design of an assembly. Support for the term paper was supplemented by the option of weekly submission and correction of interim results, which cannot be done manually due to the large number of calculations and interim results required and the number of students participating. The implementation of the term paper assessment, the associated challenges, and the experience gained are summarized below.

Im Fach Maschinenelemente wird die Vermittlung des Lehrinhalts in den Vorlesungen, den Übungen und dem Vorrechnen durch die semesterübergreifende Erstellung einer Belegarbeit ergänzt, in dem die gewonnenen Erkenntnisse zur Auslegung und Gestaltung von Maschinenelementen selbständig zur Gestaltung einer Baugruppe eingesetzt werden sollen. Die Betreuung der Belegarbeit wurde um die Möglichkeit einer wöchentlichen Abgabe und Korrektur von Zwischenergebnissen ergänzt, die aufgrund der Vielzahl an erforderlichen Berechnungen und Zwischenergebnissen sowie der Anzahl der teilnehmenden Studierenden nicht händisch erfolgen kann. Die Umsetzung der Belegbewertung, die damit verbundenen Herausforderungen und gesammelten Erfahrungen sind nachfolgend zusammengefasst.

*Corresponding author: thomas.rosenloecher@tu-dresden.de

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1. Machine Elements

At the Technische Universität Dresden third- and fourth-semester students learn the basic knowledge of machine elements that is important for mechanical engineering in three semester hours of lectures, two semester hours of exercises, and one semester hour of calculation tutorials in the summer semester. At the beginning of the winter semester, the lecture deals with the determination of load assumptions and strength calculations, which form the basis for further mathematical proofs for the various machine elements. Building on this, students learn the design procedure and basic rules for the construction of shafts, the design options for connections between shafts and hubs, and the calculation and design rules for bolted connections, springs, and couplings. The course then covers the design and dimensioning of roller bearings, plain bearings, and gear drives. The exercises serve to independently apply the knowledge learned through tasks on various topics. A detailed explanation at the beginning of the weekly classes enables students to quickly familiarize themselves with the topics, help them to understand the formulas and diagrams, and prepares them to work on the exercises independently. The calculation tutorials in the summer semester provide in-depth insight into how to find solutions using various calculation tasks.

In addition to the courses for the mechanical engineering program, the fundamentals of machine elements are offered as Design Theory for the mechatronics, renewable energy systems, economics, and textile and clothing technology programs. Due to the halving of the weekly semester hours compared to the module scope for the mechanical engineering program, only selected topics are covered in a reduced scope. It becomes particularly clear during the exercises that the prior knowledge that students can contribute varies greatly and must be taken into account when introducing the individual courses.

2. Term paper

For all the aforementioned degree programs, students must complete a term paper during the module, in which they apply and deepen

their acquired knowledge to design and engineer an assembly consisting of a shaft with bearings, a gear, and a pulley (Fig. 1).

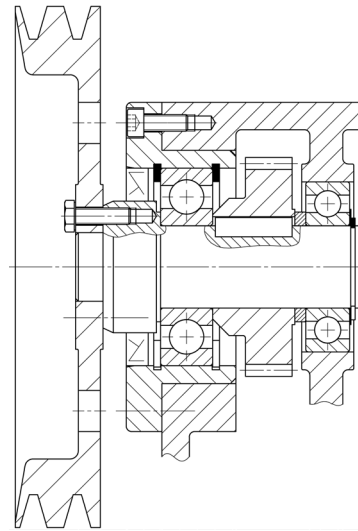


Fig. 1: Excerpt from the drawing for the assembly

The assembly is already familiar to students of mechanical engineering from courses in the second semester. Depending on the first letter of their first and last names, students are given different specifications for the shaft material to be used, the bearing distance, the position of the gear wheel and the belt pulley, the power and the gear parameters. Based on this data, the first step in completing the term paper is to determine the forces acting on the gear wheel and the belt pulley and to calculate the resulting support reactions (Fig. 2). With the knowledge of the bearing forces, the bending moments, and the torque, a rough determination of the required shaft diameter in the area of highest stress can be made. For the minimum shaft diameter in this case, the feather key or shrink fit connection must be designed, a shoulder for the fixed bearing must be created by increasing the shaft diameter, and the bolted connection between the pulley and the shaft must be designed. Shaft shoulders and the feather key nut are critical areas for a fatigue-resistant shaft design, so that the fatigue strength must be verified at these two points on the shaft. Finally, the bearing service life for the fixed and loose bearings must be determined and, based on the geometric parameters developed, a production-oriented single part drawing and an assembly drawing of the assembly with a housing must be created.

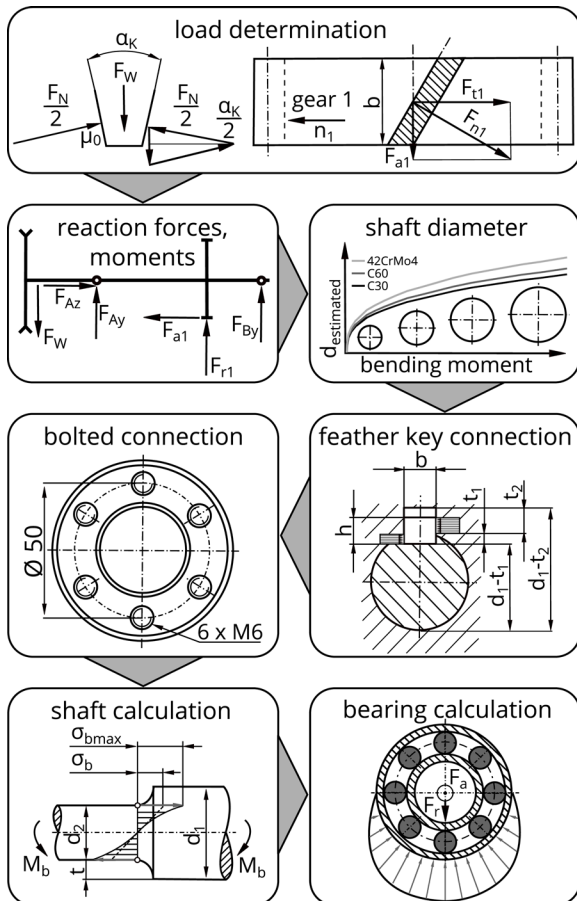


Fig. 2: Schematic sequence of processing

The term paper must be submitted with a complete documentation of the calculations, drawings, a parts list, and an assembly instruction. Support for the term paper is provided in the exercises, in a forum on the OPAL learning platform, and, in some cases, individually after classes, in personal discussions, and via email. Due to the long processing time over the entire module period, students have tended to start working on the term paper very late in the past, which made it difficult to carry out exercises, especially in the last few weeks before the deadline, due to the large number of questions that arose, and meant that the supervision of the term paper required an enormous amount of time concentrated in a short period. Several additional tutors were required to answer questions, especially in the Design Theory exercises.

3. Continuous course supervision

Driven by the high teaching and supervision workload at the end of each winter semester in the subject of Design Theory, the goal was to

create a tool that would prompt students to use the content taught in the exercises as soon as possible to work on the subtasks of their term paper. This should enable students to deepen and consolidate the knowledge they have acquired in a timely manner, clarify open questions on the individual subtasks directly in the forum or during the class, ideally ensure comparable progress among all students, and help students avoid starting their work right before the deadline. As an incentive for students, a weekly interim check of the results is offered, but due to the more than 60 students enrolled, this cannot be done manually.

In order to implement the desired interim checks, the entire calculation process for the term paper is mapped in MATLAB, taking into account the variety of variants described above. In addition to entering formulas, it is necessary to implement tables for feather keys, bolted connections, tolerances, and bearings, as well as to programmatically map diagrams that cannot be described with formulas. Students are provided with a result overview in the form of an EXCEL spreadsheet in which the calculation results can be entered (Fig. 3). This file can be uploaded to the learning platform OPAL in a submission folder by a specified deadline.

The files must then be downloaded manually. The result overviews are stored in a complex folder structure in a compressed archive. MATLAB is used to automatically unzip these archives, create a list of students who have uploaded a file, load the result overviews individually, read out personal details and the essential input data, calculate the results for the respective term paper variant using this data, compare them with the entered values, and mark the correctness with red or green in the overview. At the same time, an evaluation table is created in which the results of the correction are saved for each student. After the overviews have been successfully corrected, the documents can be sent automatically by email using another script. If the correction process runs without errors, the handling of the EXCEL files is particularly computationally intensive, so that, depending on the available computing technology, the correction time is between 15 and 30 seconds per document. The scripts have not yet been optimized in terms of computing time.

Overview of results of the term paper

First name:	<i>fill in!</i>	Last name:	<i>fill in!</i>	Student-ID	<i>fill in!</i>
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First name (1. l.)		a=	0 mm	M _{tan} =	0,00 Nm, nominal
Last name (1. l.)		b=	0 mm	F _w =	0,00 N for M _{tan}
		c=	0 mm	F _t =	0,00 N for M _{tan}
				F _r =	0,00 N for M _{tan}
				F _a =	0,00 N for M _{tan}

Bearing forces calculated based on input power:

Width of the bearing A:	0,0 mm	Gear center - position 2	0,0 mm
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nominal load [N]		with operation factor		with impact factor [N]	
F _{Ax} =	0,00	F _{Bx} =	0,00	F _{Ax} =	0,00
F _{Ay} =	0,00	F _{By} =	0,00	F _{Ay} =	0,00
F _A =	0,00	F _B =	0,00	F _A =	0,00

Fig. 3: Excerpt from the result overview

4. Practical application

In the winter semester of 2022/23, the checking of interim results was offered to students in the Design Theory course for the first time. To avoid problems when filling out and exchanging the data sheets, the template for entering the interim results is made available unprotected at the beginning. The first challenges arise in specifying the appropriate variant for checking name-dependent parameters. The variant number should be entered, but often the initial letters or a range of letters are entered, so that free entry is quickly replaced by a selection list. A similar procedure is required for entering the shaft and bore tolerances (e.g., H7) for recalculating the shrink fit. Further challenges arise from the use of a period instead of a comma as the decimal separator in the result overviews, as this is not checked in the script from the outset and text is transferred instead of numerical values. A check of the input values and, if necessary, a conversion is added to the script retrospectively. In addition, the cells for entering values in the result overviews will be formatted and the worksheets protected. Frequent queries regarding the pending return of corrected documents arise due to the uploading of PDF files instead of EXCEL overviews, missing names, mixed-up first and last names, and missing or incorrect student ID numbers, which are required to determine the email addresses for the return of documents.

During the development of the script, an EXCEL file is used to calculate interim results for the

term paper, and various exercises are used to test the programmed modules. Despite intensive preparation and checking of the script, corrections to the calculations have to be made during the interim checks. In discussions with individual students and when discussing the calculation method, errors were found and corrected in the scripts. However, some of the corrections made meant that the correct results from the previous week were incorrect in the subsequent correction. The students' dissatisfaction had to be appeased by offering additional possibilities for interim submissions.

5. Evaluation

The time required to correct the result overviews was very high in the 2022/23 winter semester. In addition to making the corrections, the script had to be adjusted at least once a week to catch incorrect entries or formatting errors. In addition, there were extensive questions in the forum, by email, and in personal conversations. The script and template developed are also being used in the Machine Elements course since the 2023 summer semester. The time required for this has been significantly reduced.

In the 2023/24 academic year, interim submissions of the result overviews were offered for the first time over the two-semester module period between the beginning of November and the end of May, a total of 19 times. The evaluation of the information provided on the individual submissions and the progress made

by each student was initially carried out manually. Due to the extensive data and the objective of continuous evaluation in each semester, the collection of statistical parameters was also implemented using scripts.

The number of students who submitted their result overview is shown above the submission deadlines in Fig. 4. It is clear that only about one-fifth of the students took advantage of the first eleven opportunities to submit their results in the 2023/24 winter semester. From the beginning of the summer semester (bar 12), the number of participants rose significantly until three weeks before the submission deadline and remained at a high level even during the last two submission opportunities.

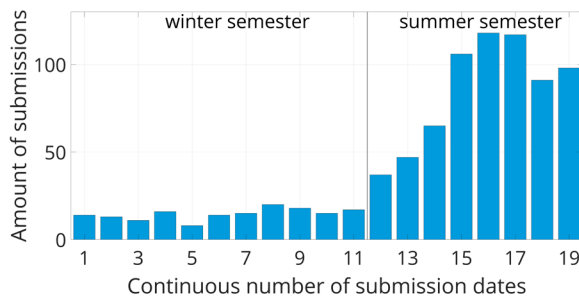


Fig. 2: Number of result overviews submitted on the 19 dates; multiple submissions were possible

A total of 165 students submitted their documents, and more than 91% of students took advantage of the opportunity to submit interim submissions at least once. On average, students used the interim submission option 5.1 times. Fig. 5 shows the distribution of students across the number of possible submissions and illustrates the resulting average.

The distribution clearly shows that the majority of students did not begin working on their coursework until the summer semester, meaning that a maximum of eight submissions were possible. Only about 8% of students took advantage of the opportunity to submit more than nine times. In contrast, 20% of students took advantage of the offer less than three times. Interestingly, the distribution of the number of students plotted against the frequency of submissions is comparable to the distribution of exam grades. In the middle grade range, there is a slight normal distribution. The number of students who fail, on the other hand, is disproportionately high.

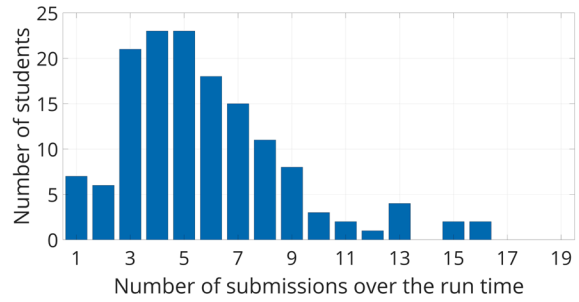


Fig. 3: Number of students plotted against the frequency of use of interim submissions

An exemplary evaluation of the performance achieved in relation to the number of interim submissions used for the period mentioned shows (Fig. 6) that an average of at least two submissions were required to achieve at least 50% of the points, and that the average percentage of points rose almost continuously to 100% after ten interim submissions.

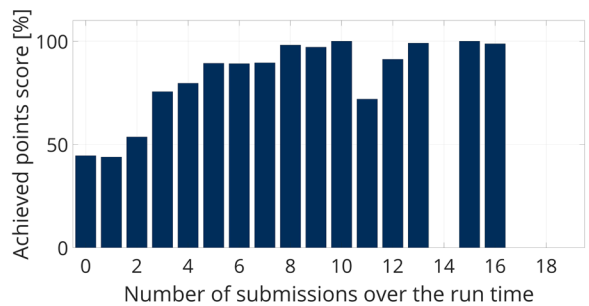


Fig. 4: Results of the course assessment in relation to the number of interim submissions

Almost 80% of students who started in the winter semester achieved 90% of the points in the calculation. Only 40% of students achieved this rating when they started in the summer semester. The grade is based equally on the corrected calculation results and the drawings. Due to the small number of students who submitted their interim results more than nine times, the values given for the average score are not representative. A statistical evaluation in a longitudinal study will be possible in the future.

6. Summary and outlook

The offered interim check of the calculation results is intensively used by a large number of students and, at the same time, provides an opportunity for a better overview of their progress, status, and challenges while working on

the term paper. When students receive feedback on incorrect results, they question the approach to solving the subtasks more closely. This offers a good basis for ensuring that the knowledge to be learned can be taught in a more targeted manner. After completing the term paper, interest in the corrected calculation is often low and the causes of errors are not questioned. The introduction of interim corrections has made it possible to shift the learning process into the working time. By taking advantage of the opportunity to submit interim assignments, students can demonstrably improve their achievable score in the calculation section. The findings and results will be incorporated into communication with students and used in the exercises as an incentive to start working on term paper early.



Gaze pattern: Investigation of strategies for dealing with indirectly proportional function graphs in a thermodynamic context

P. Fehlinger^{1*}, S. Becker-Genschow², B. Watzka¹

¹ RWTH Aachen University, Institute of Physics IA, Didactics of Physics and Technics, Sommerfeldstraße 16, 52074 Aachen, Germany

² University of Cologne, Faculty of Mathematics and Natural Sciences, Digital Education Research, Herbert-Lewin-Straße 10, 50931 Cologne, Germany

Abstract

The ability to distinguish mathematical functions is crucial for understanding complex concepts in mathematics and physics. Differentiating graphs of indirectly proportional functions from other power functions poses significant challenges for many students, which is reflected in their strategies. This study examined the gaze behavior of 80 tenth-grade students when identifying isothermal changes of state in p - V diagrams. Using gaze data and retrospective interviews, two primary strategies were identified: a focus on value pairs, where pressure and volume values were compared, and a focus on the graph of function, where the curve's trajectory was analyzed. Students who focused on value pairs exhibited mostly horizontal and vertical gaze movements, while those concentrating on the graph of function demonstrated diagonal saccades. However, many students focusing on the graph of function paid attention to irrelevant aspects, such as the position of the curve, which led to confusion between isothermal and adiabatic changes of state. The results provide insights essential for developing adaptive teaching methods that are aligned with learners' specific strategies and eye movement patterns to improve their understanding of thermodynamic function graphs.

Die Unterscheidung mathematischer Funktionen ist entscheidend für das Verständnis komplexer Konzepte in Mathematik und Physik. Besonders die Differenzierung von Graphen indirekt proportionaler und anderer Potenzfunktionen stellt viele Lernende vor Herausforderungen, die sich in den Strategien der Lernenden widerspiegeln. Diese Studie untersuchte das Blickverhalten von 80 Zehntklässler*innen bei der Identifikation isothermer Zustandsänderungen in p - V -Diagrammen. Mithilfe von Eye-Tracking und retrospektiven Interviews wurden zwei Strategien identifiziert: der Fokus auf Wertepaare, bei dem Druck- und Volumenwerte verglichen werden, und der Fokus auf den Funktionsgraphen, bei dem der Kurvenverlauf analysiert wird. Lernende, die sich auf Wertepaare konzentrierten, zeigten vorwiegend horizontale und vertikale Blickbewegungen, während der Fokus auf den Funktionsgraphen mit diagonalen Blicksprüngen einherging. Viele Lernende fokussierten sich beim Betrachten des Funktionsgraphen jedoch auf irrelevante Aspekte, wie die Lage der Kurve, was zu Verwechslungen zwischen isothermen und adiabatischen Zustandsänderungen führte. Die Ergebnisse liefern wichtige Hinweise für die Entwicklung adaptiver Lehrmethoden, die an die spezifischen Strategien und Blickbewegungsmuster der Lernenden angepasst sind, um das Verständnis thermodynamischer Funktionsgraphen zu verbessern.

*Corresponding author: fehlinger@physik.rwth-aachen.de

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1. Introduction

Current educational research is increasingly concerned with the question of how digital learning methods can be effectively integrated into teaching in order to better support individual learning processes. A central goal is to investigate how learners use different forms of representation to successfully process complex information. Function graphs play a central role in STEM subjects, as they support learners in understanding functional relationships.

A typical example of this are indirectly proportional functions in thermodynamics, which describe isothermal state changes in p-V diagrams. They play a central role in both mathematics and physics lessons in secondary education.

However, learners often have difficulty grasping the meaning of such function graphs [1-3]. In the field of thermodynamics, this is particularly evident in the fact that learners have difficulty correctly distinguishing between isothermal and adiabatic state changes in a p-V diagram [2, 3]. This is also evident in the chosen processing strategies, which are not always effective when it comes to understanding the functional relationship, as exemplified in this article [1]. The problem here is that teachers face the challenge of accurately assessing their students' learning obstacles [4].

Eye tracking data analyses offer valuable insights into learners' strategies and can contribute to the optimization of teaching methods. In this study, they are used together with verbal data to investigate how learners recognize isothermal state changes and distinguish them from adiabatic state changes.

2. Isothermal change of state

In a reversible, isothermal state change, the temperature of the system remains constant, while the pressure is inversely proportional to the volume.

The product of pressure and volume remains constant. In the p-V diagram, such an isothermal state change is represented as a right-angled hyperbola (see Fig. 1A).

In reversible adiabatic state changes, there is no heat exchange with the environment because the system is thermally insulated [5]. In the p-V diagram, such adiabatic state changes are represented as power functions that show no indirect proportionality between pressure and volume (see Fig. 1B).

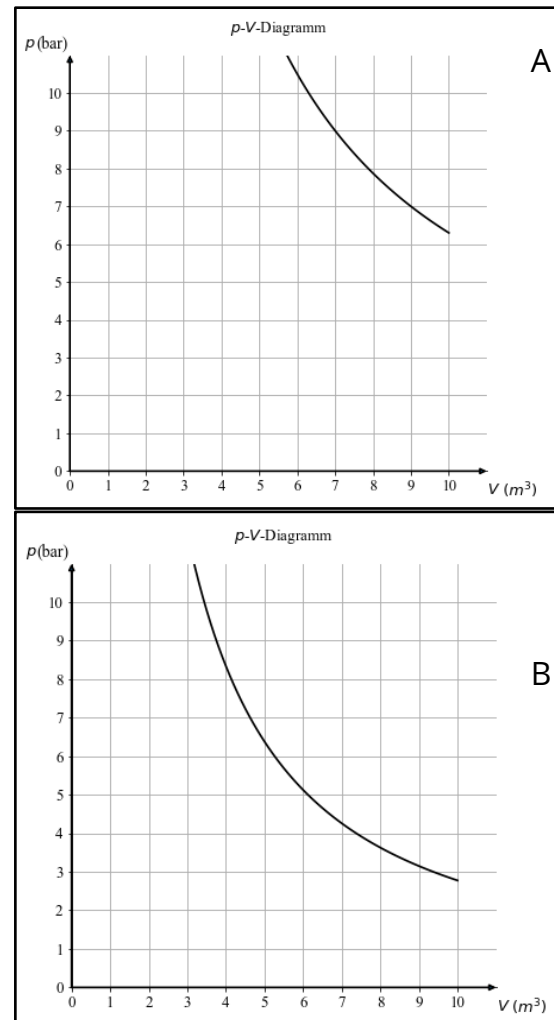


Fig. 1: Representation of an isothermal state change (A) and an adiabatic state change (B) in the p-V diagram. Item T1 from the empirical study published in PRPER [1].

Physical knowledge alone is not sufficient to interpret thermodynamic state changes. Functional thinking, which also includes mathematical understanding, is also required.

This includes, in particular, knowledge of proportional relationships, the course and interpretation of function graphs, and the relationship between variables such as pressure and volume.

Pinker [6] postulates that the understanding required to interpret a function graph is stored in the memory as a diagram scheme. Pinker [6] describes this diagram scheme as a knowledge structure that comprises information about operators that enable relevant data to be extracted from a function graph. Both essential elements of perception and processes of working and long-term memory play a decisive role in this [6].

3. Investigation of strategies

A deep understanding of the cognitive processes that learners use when working on tasks is crucial for optimizing teaching and learning processes. Eye tracking and retrospective think-aloud protocols (RLDP) are effective methods for uncovering the strategies used to solve tasks. These methods allow conclusions to be drawn about the underlying cognitive processes [7-11].

In eye tracking for the analysis of processing strategies, saccade directions are important in addition to transitions and fixations [7, 8]. Transitions show changes between fixed areas, while saccades represent rapid eye movements between fixation points. The direction of the saccades provides clues as to how texts or diagrams are read and interpreted [8].

Triangulation with RLDP enables further optimization of the analysis of processing strategies [9] by having participants reflect on their actions after completing a task [10].

In a study by Thomanek et al. [11], gaze data and verbal data were used to examine strategies for analyzing changes in graphs in real-world contexts. This allowed two main strategies to be identified.

The first was the analysis of the entire function graph curve and the section-by-section examination based on specific value pairs. The verbal

data corresponded well with the eye-tracking data and also provided valuable insights into the approaches used in the situational context [10].

This underscores the importance of eye tracking and supporting interviews to stimulate RLDP.

4. Objective

Based on the findings of Thomanek et al. [11], this study aims to classify the processing strategies of learners in identifying graphs of indirectly proportional functions in a thermodynamic context and to analyze the saccade directions in the respective processing strategies. The goal is to analyze the processing strategies used when dealing with indirectly proportional function graphs and to relate them to the saccade directions, as these play an important role in the investigation of cognitive processes. This raises the following research question: *How can learners' processing strategies for identifying indirectly proportional function graphs in a thermodynamic context be classified, and what characteristic saccade directions can be assigned to these strategies?*

By combining eye-tracking data and verbal utterances, a deeper understanding of cognitive processes is to be gained.

5. Methodological approach

A total of 80 tenth-grade students from secondary schools in a medium-sized German city participated in the study (45 female, 34 male, 1 no information provided). The average age was 15.47 years ($SD = 1.66$); one person did not provide their age. The study was divided into three parts (see Fig. 2). In the first step, the students independently reviewed thermodynamic state changes in order to reactivate their knowledge from 8th grade using a handout.

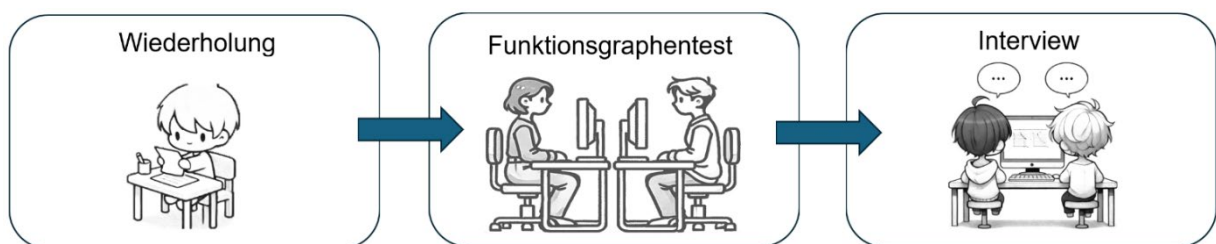


Fig. 2: Procedure of the study to investigate eye movement patterns during the identification of isothermal state changes in the p-V diagram. The image was created using ChatGPT-4o

A function graph test (see section 6) was then performed while simultaneously recording gaze data using a stationary eye tracker (Tobii Pro Fusion). Afterwards, the learners were asked questions about their approaches in order to gain a more detailed understanding of their processing strategies and to validate the eye tracking data. To assist them, the participants were shown a recording of their eye movements in the form of an eye path during the interview in order to aid their memory. A key advantage of eye tracks is that they map the processing steps step by step, enabling a detailed reconstruction of cognitive processes. Further details can be found in the study by Fehlinger et al. [1].

6. Function graph test

The study is based on a test instrument with three items in a thermodynamic context, which was developed to assess the understanding of function graphs (Cronbach's alpha = 0.75). For the present analysis, a representative item was selected that provides insight into the processing strategies of the learners. A more detailed evaluation of all items is documented in Fehlinger et al. [1].

The respective items of the test instrument were designed as multiple-choice tasks in which a distinction had to be made between isothermal and adiabatic state changes; the analyzed sample item represents a characteristic feature of this task format (see Figure 4). The goal was to correctly identify the isothermal state change.

Participants were asked to control their gaze behavior as precisely as possible so that an outsider could understand how the task was solved based on the recorded gaze paths. To make this easier, they were shown a recording of their own gaze paths from a previous task at the beginning of the study. In this way, the participants were to develop an understanding of what typical gaze paths look like and how their own gaze behavior can be represented by these gaze paths.

The test was conducted digitally, while the learners' eye movements were recorded using the Tobii Pro Fusion eye tracker. The scenario is shown in detail in Figure 3. The study leader

and the participant each sat in front of a screen. The participant worked on the tasks on a screen with an eye tracker, while the study director followed the process in real time on another screen using the gaze paths.

This made it possible to identify and document initial anomalies in the processing in order to derive specific questions for the subsequent interview using a standardized questionnaire. Detailed descriptions of the methodological approach can be found in the article by Fehlinger et al. [1].

7. Evaluation method

For the evaluation of the sub-goal defined above, one item was used as an example, as it is particularly representative of the processing strategies and cognitive processes to be investigated.

The categorization of processing strategies when dealing with the graph of the indirectly proportional function was based on the gaze data.

To this end, the corresponding diagram was divided into relevant areas such as axes, origin, labels, arguments, function values, and the function graph itself, known as AOIs (Areas of Interest) (see Fig. 4).

The relevant areas were determined based on the representation of fixations in the heat maps (see Fig. 5).

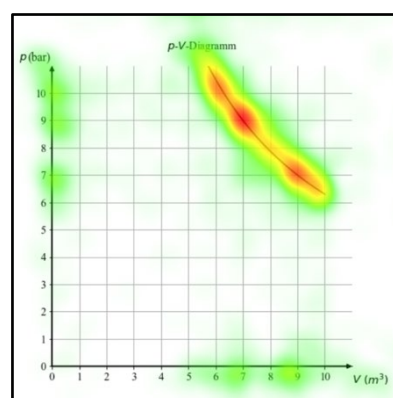


Fig. 5: Heat map showing the cumulative total fixation time over the entire processing time of 80 learners. Red = high, green = medium, yellow = low fixation duration. Item T1 from the empirical study published in PRPER [1].

To categorize the strategies, the number of transitions, fixations, and saccade directions

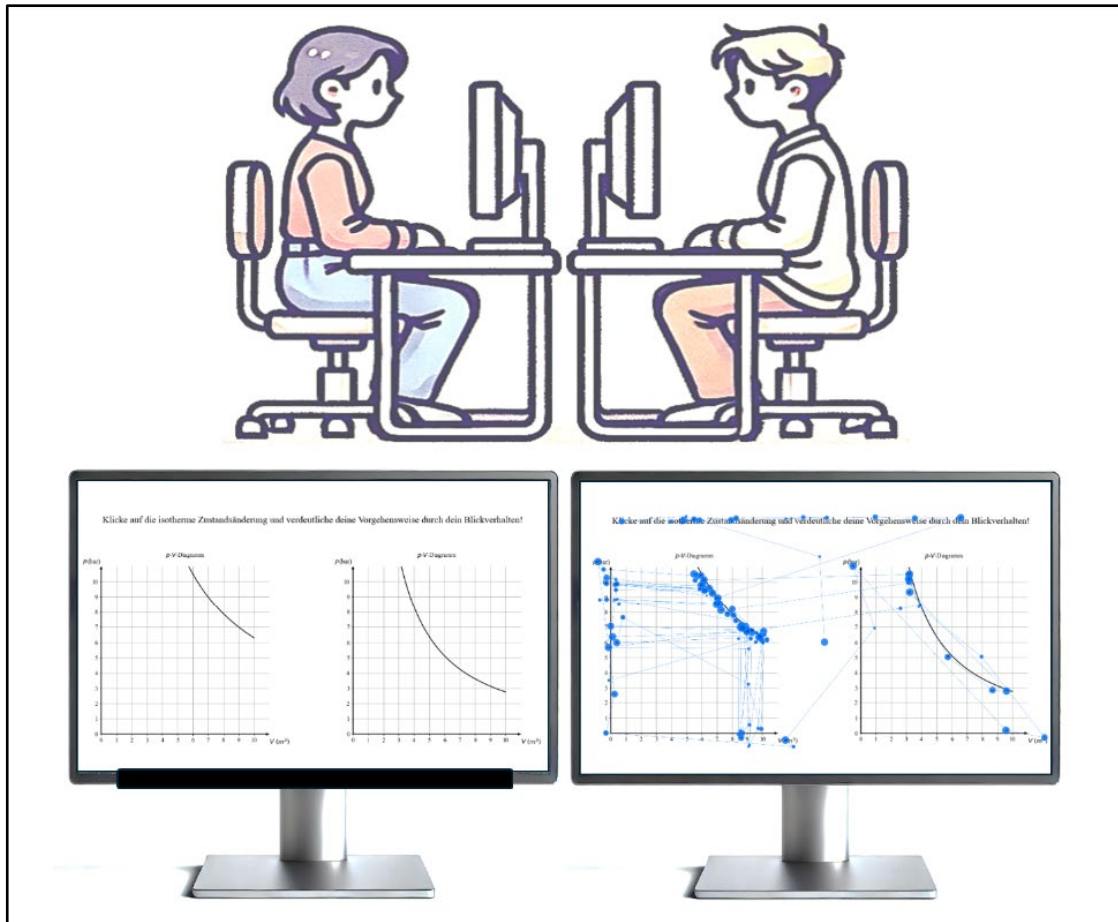


Fig. 3: Empirical experimental setup for investigating eye movement patterns during the identification of isothermal state changes in the p - V diagram. On the left, a test subject works on tasks to identify isothermal state changes while his eye movements are recorded using an eye tracker. On the right, the study director tracks the test subject's eye movements in real time. The screens show examples of the respective views of a test subject and the study director. The image was created using ChatGPT-4o. Item T1 from the empirical study published in PRPER [1].

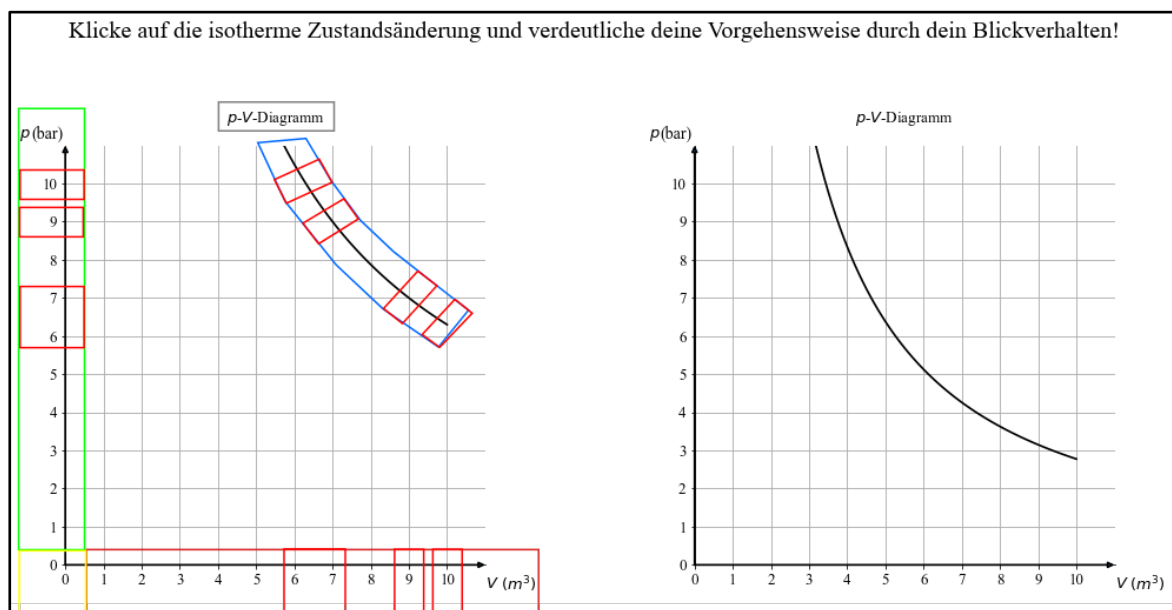


Fig. 4: Representation of areas of interest (AOIs) in the p - V diagram with isothermal state change for the investigation of strategies. Item T1 from the empirical study published in PRPER [1].

based on the AOIs were analyzed and a hierarchical cluster analysis (Ward method) was performed [12]. The verbal data was used to supplement this. For this purpose, the interviews were transcribed and subjected to a qualitative content analysis [13].

The relevant passages were then assigned to the clustered processing strategies.

In order to gain detailed insight into the gaze data of the processing strategies, the saccade directions of all participants were examined more closely, as these provide clues as to how the diagram is read and interpreted [8].

For this purpose, a kernel density estimation was applied to the saccade directions in order to represent them continuously.

8. Results

The heat map in Figure 5 already shows that the function graph, certain points on it, and the

axes with the respective values were used in particular to solve the task.

Figure 6 shows examples of the gaze paths assigned to the classified processing strategies, as well as the results of the core density estimates of the saccade directions in polar diagrams. The cluster analysis identified two strategies: the 'focus on value pairs strategy' (see Fig. 6A) and the 'focus on function graph strategy' (see Fig. 6B).

In the "focus on value pairs" strategy, learners switch between points on the function graph and the axes (see Fig. 6A). The interviews reveal that they analyze two states of change by comparing the pressure and volume values. In doing so, they check whether the pressure of the first state corresponds to the volume of the second state and vice versa. One test subject explains:

"I compared the points to see if they changed by the same factor. And that was the case. That's why I decided to do it."

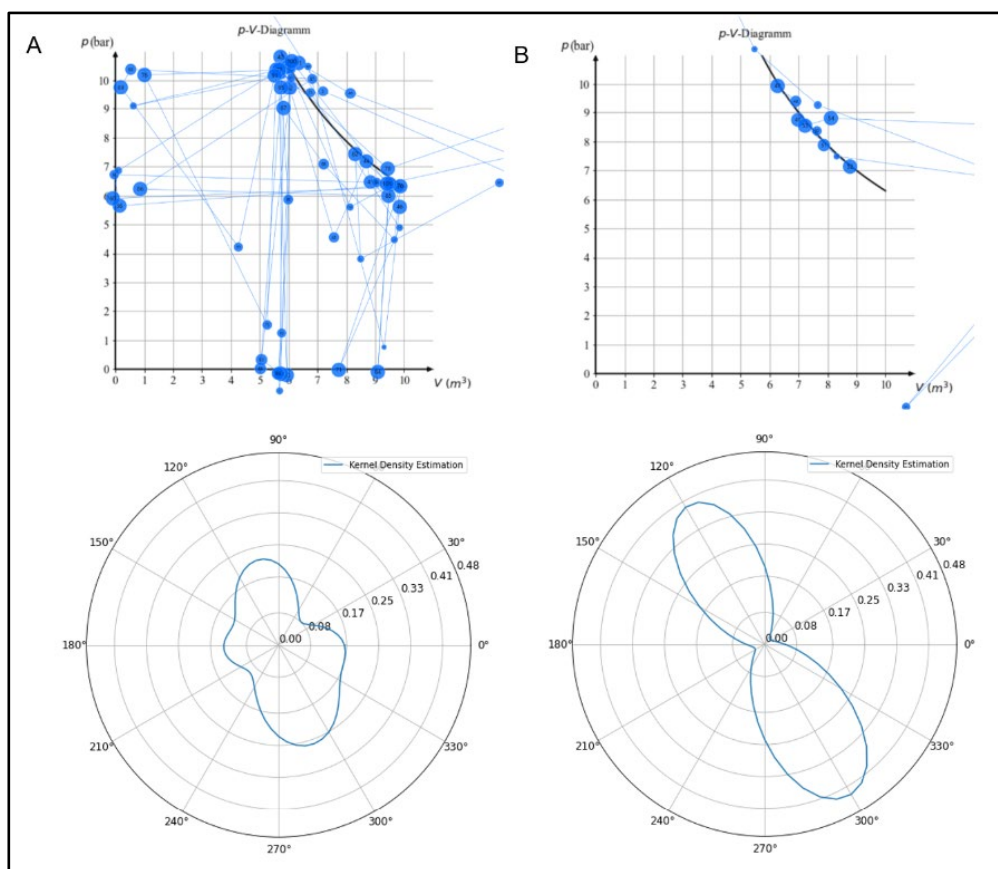


Fig. 6: Exemplary gaze paths for the processing strategies Focus on value pairs (A) and Focus on function graphs (B). The lower figures show the kernel density estimates (KDS) of the saccade directions for the respective processing strategies. Item T1 from the empirical study published in PRPER [1].

The eye movements are predominantly horizontal and vertical (see Fig. 6A, polar diagram). The "focus on the function graph" strategy concentrates on the course of the function graph (see Fig. 6B).

According to interviews, learners primarily analyze the course and position of the curve to identify typical characteristics of isothermal state change. One test subject says, for example:

"... but it's just more curved than the other one. The other one is almost a straight line, well, almost. And that's why I chose the other one."

The saccade directions run diagonally (see Fig. 6B, polar diagram). The gaze patterns and verbal data reveal different approaches and difficulties.

9. Discussion

Clustering based on gaze data and analysis of saccade directions provide valuable insights into the processing strategies used by learners to identify isothermal state changes in the p-V diagram. In addition, the verbal data offer deeper insights into the processing strategies and reveal learning difficulties that hinder successful identification.

Two processing strategies were identified that are similar to those from the study by Thomanek et al. [11]. The participants were evenly distributed across both strategies (50% each). On the one hand, the function graph was analyzed section by section using specific pairs of values, which is reflected in predominantly horizontal and vertical saccades. On the other hand, the graph was considered in its entirety, with diagonal saccades in particular indicating a holistic understanding of the function curve.

The analysis of the value pairs in particular represents a solid processing strategy that closely resembles a product equality test. Focusing on the function graph proves to be a successful strategy when learners check whether the graph shows the course of a right-angled hyperbola. However, this strategy for identifying isothermal state changes becomes prone to error when the focus is placed on the position of the graph, for example. Focusing exclusively on the position of the graph—for example, whether it runs "above" or "below" in the dia-

gram—can lead to misinterpretations, as isothermal and adiabatic state changes can be similar in their graphical representation under certain conditions. The decisive difference, however, lies in the functional course of the curve, which cannot be determined solely by its position in the diagram. This points to difficulties learners have in dealing with graphs of indirectly proportional functions. Detailed information on the processing strategies can be found in the study by Fehlinger et al [1].

From a future-oriented perspective for adaptive support systems, it is a great advantage that the saccade directions exhibit specific characteristics in the respective processing strategies. These enable precise conclusions to be drawn about the learners' approach based on their eye movement patterns, allowing individually tailored assistance to be implemented in a targeted manner.

10. Conclusion

Previous studies have shown that learners often have problems analyzing function graphs, while teachers often fail to recognize these difficulties [2–4]. However, there are fundamentally suitable didactic approaches—such as the use of multiple forms of representation, the conscious switching between different representations, or the use of interactive visualization tools—that can specifically contribute to the promotion of these skills.

The analysis of eye movements and verbal data provides valuable insights into the processing strategies and specific learning difficulties of learners.

A key lesson learned is that learners often focus on irrelevant aspects when looking at graphs and therefore find it difficult to distinguish between isothermal and adiabatic processes. This highlights the need for targeted assistance to improve understanding of thermodynamic state changes.

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