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Interactive exercise tasks in physics education: comparison between online, face-to-face and self-study instruction

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Abstract

Lernen ist ein aktiver und konstruktiver Prozess. Interaktive Aufgaben erlauben eine Aktivierung der Lernenden in jedem Lehrformat. Offen ist die Frage, ob es Unterschiede im Bearbeitungserfolg und der Änderung des Professionswissens beim Lernen mit interaktiven Aufgaben unter verschiedenen Lehrformaten gibt. Ebenso ist offen, inwieweit sich angehende Lehrkräfte vorstellen können, mit Hilfe eines Tools solche Aufgaben selbst zu erstellen und in ihrem späteren Berufsleben als Lehrmittel einzusetzen.
Ein interaktives Aufgabenset wurde mittels drei verschiedener Methoden gelehrt und evaluiert. Die Stichprobe (N=66) stellten Lehramtsstudierende der Physik. Sie bearbeiteten einen Lernpfad mit interaktiven Aufgaben, um sich fachdidaktisches Wissen zu einem Thema zu erarbeiten und zugleich ein Tool für die Entwicklung solcher Aufgaben kennen zu lernen.
Die Ergebnisse zeigten keine signifikanten Unterschiede im Bearbeitungserfolg und Professionswissen zwischen der Online- und Präsenzlehre. Jedoch zeigten die im Selbststudium Lernenden signifikant kürzere Bearbeitungszeiten, ein chaotischeres Lernverhalten, einen geringeren Bearbeitungserfolg und geringere Zuwächse im Professionswissen. Die Akzeptanz der Studierenden in Bezug auf interaktive Aufgaben und das exemplarische Tool stieg durch die Arbeit mit dem Aufgabenset in allen Gruppen an.

Learning is an active and constructive process. Interactive exercise tasks (IET) enable the activation of learners in any teaching format. It is an open question whether there are differences in the task success and the change of professional knowledge when learning with IET under different teaching formats. It is also open to what extent prospective teachers can imagine creating such tasks themselves with the help of a tool and using such tasks in their later professional lives.
An IET set was taught using three different methods and evaluated. The sample (N=66) consisted of student teachers of physics. They worked on a learning path with IET to acquire educational knowledge and at the same time to get to know a tool for the development of IET. The results showed no significant differences in task success and professional knowledge between online and face-to-face teaching. However, self-study learners showed significantly shorter learning times, more chaotic learning behaviour, lower task scores, and lower increase in TPACK. The students' acceptance of IET and the exemplary tool increased in all groups as a result of working with the tasks.

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1. Introduction

The COVID-19 pandemic challenged lecturers to break the rather passive consumer attitude of some students in online/distance learning [1] and instead promote active student engagement with the learning materials.

This paper describes the evaluation of learning paths with interactive elements/tasks in asynchronous and synchronous online and face-to-face teaching in teacher education. The main goal of the courses is to teach physics educational knowledge and technology-related physics educational knowledge. The procedure of the course extends cyclically over two sessions. In the first session, students work on physics educational topics, which are prepared by the lecturer via a tool. In the second session, the students acquire practical knowledge about the tool that was used to prepare the learning content in the previous session. In this way, the students can take on the roles of learners (first session) and teachers (second session).

In this article, an excerpt from the area of the first sessions is presented. With an interactive learning path, physics educational knowledge about the transistor is taught. The learning path is implemented with the tool H5P.

2. H5P

H5P enables the creation of interactive learning content and is a freely accessible and open-source software. It is available as a plugin for various content management systems (CMS) such as WordPress and learning management systems (LMS) such as Moodle [2].

H5P is configured with an LTI and an xAPI interface.

LTI stands for Learning Tools Interoperability and is a universal standard that enables the integration of a system (here a H5P task) into other systems (e.g. Moodle) [3].

xAPI stands for Experience API and is also known as TinCan [4]. The xAPI interface passes data to a learning activity database, also known as a Learning Record Store (LRS). The xAPI statements are based on the simple pattern: subject verb object. This allows tracking of any activity of a learner in the learning environment [3].

3. Effects of active learning

Active learning is anything that gets students to do things and to think about what they are doing [5].

Initiating learning activities in lectures can improve learning performance [6]. For example, Hake [7] shows that student performance increased significantly in introductory physics courses, when interactive methods were frequently used.

The learning benefits of interactive content have been recently explored by several users from different academic disciplines (including Watzka et al. [2], Pereira et al. [8], Chen et al. [9], Rama Devi et al. [10], Unsworth and Posner [11], López et al. [12], Sinnayah et al. [13], Wilkie et al. [14], Wicaksono et al. [15], MacFarlane and Ballantyne [16], Mir et al. [17], Thurner et al. [18], and Santos et al. [19]). In the following, only the results of evaluations of H5P content, that were measured in a standardized way with log files or xAPI data, questionnaires, or interviews are reported.

Thuner et al. [18] conducted a mixed-method study on the effect of interactive videos [18]. They collected log files, questionnaires, and problem-based interviews. Among other things, they investigated learning behavior and learning outcomes when working with interactive or non-interactive H5P videos. Their results show that H5P quizzes implemented in videos influence learning behavior. Compared to the group without H5P quizzes, the group with the quizzes used the questions as navigation aids. The log files show that quite a few users, for example, first jump to the quiz questions to check the expectations set for them. After that, they decide if it makes sense for them to watch the video sections. In the interviews, the users confirm the focusing effect of the quiz questions and they state that they help them to process the video content.

Wicaksono et al. [15] conducted questionnaire studies with open and closed questions. They investigated for 19 students whether their motivation and learning performance in English is influenced by the use of H5P content. Their results show that 90% of the participants agree with the question about whether H5P content helps them to focus on relevant details. Similarly, 90% of participants feel more interested and attentive to the learning content because of the use of H5P content. Another 74% say they are more motivated by using H5P content. A large number of the motivated students also have achieved good learning performance, which Wicaksono et al. [15] see as a trend towards a positive relationship between motivation and learning performance.

Sinnayah et al. [13] asked 250 students about the use of H5P content in physiology courses by using a questionnaire. Their results show that 80% of the students perceive the H5P content to be more time-consuming compared to the multiple-choice questions they usually use. Despite the increased effort, 90% of students report that their knowledge has improved through repeated practice with H5P, and that H5P content helps them to keep up in the course.

Santos et al. [19] used the H5P template *Branching Scenario* in terms of interactive problem-based simulations in a network course with 30 students. They captured the learning behavior of the students using xAPI. They also compared the final grades of the course with H5P content with the grades of previous courses without H5P content. The results show that students who learn with H5P content achieve better grades on an average while being extremely satisfied with their exercises. Students also believe that learning with H5P content helps them to learn concepts faster.

4. Learning paths and routes

Learning paths are idealized, often linearly structured learning opportunities. They are often implemented as web-based learning environments in a modular way. They provide binding learning goals and contain various interactive learning materials with coordinated tasks. They also include feedback and offer help to achieve the goals. Depending on their interests and level of performance, learners can independently select units or tasks and thus direct their individual learning process toward the given goals [20]. Learning paths do not force the learner to work through the material in a linear way; rather, they leave it up to the learner to decide on varying individual learning routes [21].

Learning routes show the sequences of the units called up and the tasks worked on as a function of time. Despite a linear learning path, learning routes often do not run in a linear way. They can oscillate and are characterized by jumps [21]. Causes for different learning routes are not only individual knowledge structures of the learners, which have already been formed due to previous experience and knowledge [21]. Affective components such as interests or attitudes can also influence the selection of a learning path. Analyzing learning routes is not just about examining the successes and failures at the end of a learning process. Rather, the goal is to visualize the genesis of successes/failures during the learning process.

Measures of learning routes are, for example:

- Time points and durations of the processing of tasks / units
- Frequencies incl. repetitions and omissions of tasks / units
- Sequences of the activities
- Achieved scores, deductions due to errors
- Frequency of the call for help
- Log files e.g. for using the navigation options etc.

5. Teaching objectives and evaluation goal

The seminar aims at applying educational theories to a concrete teaching content and enhance the students' competencies in the field of multimedia learning.

The aim of the evaluation is to record the learning outcomes (the scores for tasks and changes in the professional knowledge), the acceptance and relevance in relation to the interactive tasks and the chosen learning routes. The theoretical basis is based on TAM models extended by TPACK as described by Mayer et al. [22].

A comparison of the learning effect between learning with interactive tasks and a classical lecture style or an experimental practical course is not of interest here. Also, possible connections between the choice within a learning path and interest characteristics or motivational dispositions are not in question here.

6. Sample and procedure

The sample consists a total of 66 student teachers studying physics for the teaching profession at LMU Munich (n=55, 33 of them male) and OVGU Magdeburg (n=11, 8 of them male). The Munich students were between the 7th and 9th semester, the Magdeburg students had completed the 6-semester Bachelor's program and were in the 1st semester of the Master's program. All students had already attended the physics experimental lectures, the introductory to physics education lecture and the experimental laboratory courses as well as two seminars on typical school experiments. Furthermore, all students were familiar with the processing of interactive tasks.

The evaluation took place in three winter terms (19/20, 20/21, and 21/22) in a 90-minute compulsory course. The distribution of the students to the teaching format was not done randomly, but according to the Corona regulations at that time. An overview of the number of participants per teaching format is shown in the following table (Tab. 1).

Tab. 1: Sample

	Guided Online	Guided Face-to-face	Not guided Online (self-study)
M	33	10	12
MD	--	8	3

Prior to learning with the interactive learning path, all three groups were initially asked about their professional knowledge, their acceptance of interactive tasks in general, and the perceived relevance of such tasks for their later professional life. Also control variables such as gender, semester, and degree program were asked (pre-test).

Subsequently, guided learning through the learning path with the interactive tasks took place in the online and face-to-face teaching groups. For this purpose, the students and the lecturer opened the web-based learning path on their own devices. The lecturer moderated the routes through the learning path by initiating changes between slides or tasks. The learning activities of the students were continuously recorded. Immediately after completing the learning path, the participants completed the post-test.

The self-study group worked through the learning path with the interactive tasks at home without instructional guidance. The post-test directly followed the completion of the learning path.

7. Learning path with interactive tasks

The learning path uses the H5P template Branching Scenario and is designed for a processing time of 90 minutes. It contains elements that build on each other and three specialized educational topics. Fig. 1 shows the external structure of a learning path in editing mode. The black boxes stand for interactive presentations that can contain one or more learning contents and interactive tasks. The blue boxes stand for selection questions, which then lead to the different educational topics. The arrows contained in the red circles represent the possibility to return to the selection question after a topic has been worked on. The red flag marks the end.

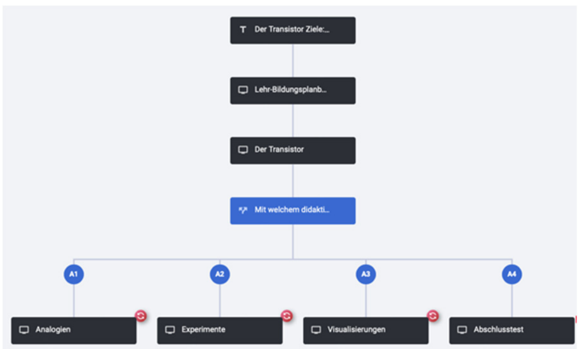

Fig. 1: Structure of a simple learning path. The path is linear, but leaves the option open for jumps.

In addition to information, the interactive presentations also contain literature references, supplementary aids and tasks for exercises (see Figs. 2 and 3). In interactive presentations, as shown in Fig. 2, the content is always at the center of the slides. The blue circles with an i in them lead to additional help. The purple circles stand for interactive tasks (see Fig. 3).

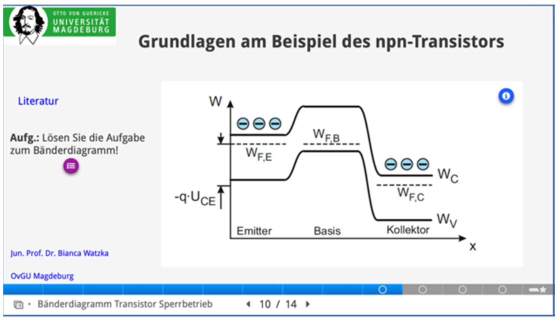

Fig. 2: Excerpt from the interactive presentation on the basics of the npn transistor. In the center you can see the band model. Literature references and interactive tasks can be opened on the left. On the right, help can be displayed.

The interactive tasks were selected according to the needs of the content and are therefore mostly implemented in multiple-choice or drag-and-drop format.

In the case of multiple-choice questions, known misconceptions can be used as response alternatives. In this way, it is also possible to search for incorrect thought patterns during the analysis.

Drag-and-drop formats are suitable for iconic representations of models, because here the mapping of reality into the model can be done by assigning.

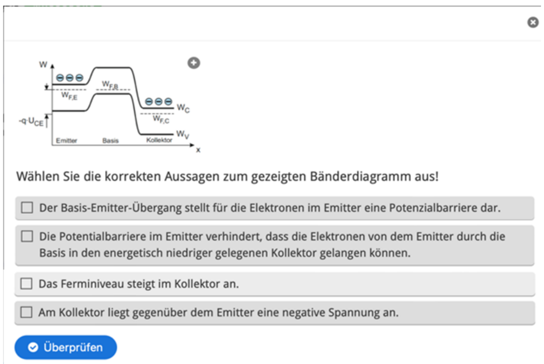

Fig. 3: Example of an interactive multiple-choice task on the band model showing a npn transistor.

Each unit is followed by a summary with the scores achieved on the tasks, which are then also automatically documented in the LMS (see Fig. 4).

Fig. 4: Example of a summary. The achieved scores are summed up here. There is also the possibility to display the task solutions and to repeat the section.

The selection questions (Fig. 5) are the trademark of the Branching Scenario template. They are formulated neutrally and lead to the educational topics. Due to the various requirements, each topic contains different task formats.

Fig. 5: Selection question with in-depth options. The question is: "What didactic issue do you want to deal with?" Choice options are: analogies, experiments, visualizations and final test.

For example, in the *Experiments* section interactive experimental videos are included as a task format (see Fig. 6), because they can be used to replicate how experiments are set up and performed.

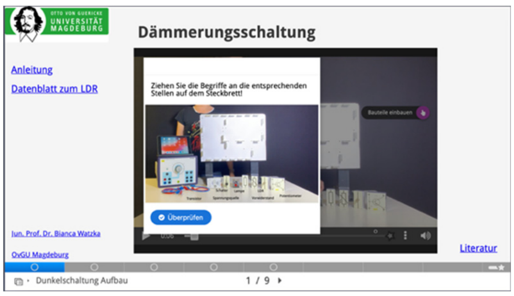

Fig. 6: Excerpt from an interactive video showing the setup of a light-sensitive circuit. The components can be placed on the board via drag-and-drop.

The situation is different for the topics *Visualizations* and *Analogies*. Here, visualizations have to be classified according to image types and then their function in learning processes has to be determined or analogies have to be evaluated according to Issing's criteria. For such activities, cloze exercises, multiple-choice tasks, and true/false statements are particularly suitable task formats.

Fig. 7: Example of true/false statements for the evaluation of analogies according to Issing. In the background you can see the water lock analogy. In the front there is a statement about the familiarity of the image.

The final test at the end of the learning path is based on the TPACK questionnaire [20] and has been specified regarding to the topic of *transistors*. It is a student self-assessment which can provide information about the learning success in addition to the scores achieved on the tasks.

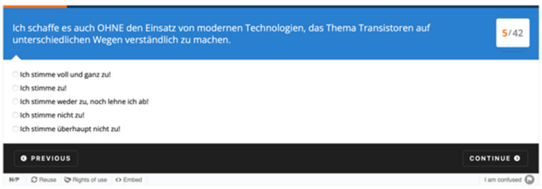

Fig. 8: Exemplary student self-assessment question at the end of the learning path. Statement: "I manage to make the subject of transistors understandable in different ways even without the use of modern technologies."

8. Variables and instruments

The measurement captured outcome and process variables. Outcome variables included perceived acceptance towards interactive H5P content and its relevance for later professional life as well as facets of teacher professional knowledge (TPACK).

Established scales were used to collect the outcome variables, including:

- Perceived acceptance towards the interactive learning material (cf. [22], 2 items),
- Perceived relevance of interactive learning materials for later professional life (cf. [22], 8 items) and
- TPACK (cf. [22], 32 items).

The standardized survey instruments are 5-level Likert scales. They range from "I fully agree" to "I strongly disagree".

For the analysis of the learning routes, the following variables recorded by the xAPI interface were assigned to the process variables category: Processing times, processing successes / scores, repetitions, sequences, and aborts, as well as jumps between information units and tasks, etc.

9. Data Analysis

Changes in professional teacher knowledge as well as changes in acceptance and relevance were determined by the Hake factor g, which indicates the average normalized increase. It is defined as the ratio between the average increase, resulting from the difference of post- and pre-test, and the maximum possible increase, resulting from the difference of the maximum value and the pre-test value [6].

Independent samples *t-tests* were used to test whether there were differences in the increases in perceived acceptance and relevance between the teaching formats. Due to the small sample, a bootstrapping procedure with 10.000 simple random samples and a 95% confidence interval was chosen. If variance heterogeneity was found, a correction for degrees of freedom (Welch correction) was applied. Cohen's d was calculated as the effect size measure. For multiple testing related to a null hypothesis, a Bonferroni alpha error correction was applied.

The analysis of the learning routes was performed semi-quantitatively (see Fig. 8-10). For this purpose, chord diagrams were programmed in Python. The colored elements of the outer ring correspond to the units or task sets of the learning environment. The sizes of the circular arcs plotted proportionally to the mean processing times. The colored chords in the circle between the units / task sets represent jumps between units or tasks. A chord always starts at the same colored unit / task set and ends with a different colored unit / task set. The chord width is proportional to the frequency of the jump within a group.

10. Results

Table 2 shows the mean values and standard deviations for the processing time and the reached scores as well as the relative increases of TPACK, acceptance and relevance.

Results of paired samples *t-tests* each show significant increases with a small effect size between pre- and post-test for ...:

- the change in perceived acceptance ($t_{62} = 13.17$, $p < .001$, 95% CI [.499, .678], $d = 0.35$).
- the change in perceived relevance ($t_{62} = 7.70$, $p < .001$, 95% CI [.150, .255], $d = 0.21$).
- the change in TPACK ($t_{62} = 9.13$, $p < .001$, 95% CI [.267, .417], $d = 0.30$).

Results of *t-tests for* independent samples show for ...:

- the processing time a significant difference with a high effect size between the guided groups (online + face-to-face) and the self-study group ($t_{60} = 10.88$, $p < .001$, 95 % CI [14.17, 20.56], $d = 5.4$). Self-study learners discontinue their activity earlier than learners guided in face-to-face or online teaching.
- the scores a significant difference with a high effect size between the guided groups (online + face-to-face) and the self-study group ($t_{60} = 10.49$, $p < .001$, 95 % CI [20.58, 30.28], $d = 8.2$). Learners in the self-study group score lower than learners working in the guided face-to-face or the guided online teaching group.
- the change in perceived acceptance a significant difference with a small effect size between the guided groups (online + face-to-face) and the self-study group ($t_{60} = 2.46$, $p = .017$, 95% CI [.022, .209], $d = 0.16$).
- the change in perceived relevance no significant difference between the guided groups (online + face-to-face) and the self-study group ($t_{60} = 1.35$, $p = .183$, 95% CI [-.027, .141], $d = 0.14$).
- the change in TPACK a significant difference with a small effect size between the guided groups (online + face-to-face) and the self-study group ($t_{60} = 3.89$, $p = .032$, 95% CI [.073, .228], $d = 0.13$).

As expected, processing time and scores correlate highly with each other (Pearson $r = .698$, $p < .001$, 95% CI [.609, .830]).
Students spend the most time on the pages with the basic knowledge and the least time on the historical excursus.

Tab. 2: Selected mean values and standard deviations

	Online guided		**Face-to-face guided**		**Online Self-study not guided**	
	M	*SD*	*M*	*SD*	*M*	*SD*
Processing time	76.25	2.04	74.41	1.32	58.23	10.59
Scores	98.30	5.05	94.00	5.74	71.40	13.45
Hake acceptance	0.36	0.16	0.27	0.17	0.21	0.18
Hake relevance	0.20	0.14	0.07	0.11	0.11	0.08
Hake TPACK	0.26	0.14	0.10	0.08	0.06	0.08

11. Visualizations of the learning routes

Differences in the learning routes chosen by the students in the three groups are visualized by the following chord diagrams (Fig. 8, Fig. 9, and Fig. 10).

The learning units / task sets of the outer ring are: (1) learning goals, (2) applications of transistors, (3) functions of transistors, (4) visualizations, (5) basic knowledge / physics, (6) task set 1, (7) task set 2, (8) task set 3, (9) task set 4, and las but not least (10) history.

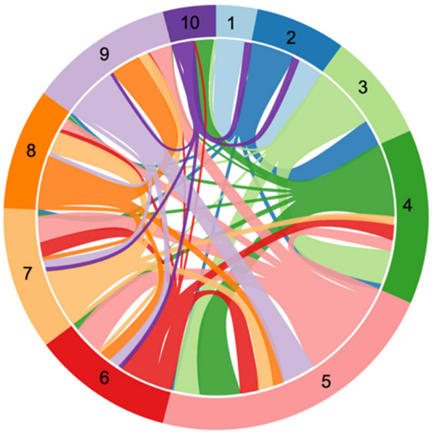

Fig. 8: Learning routes in guided online teaching.

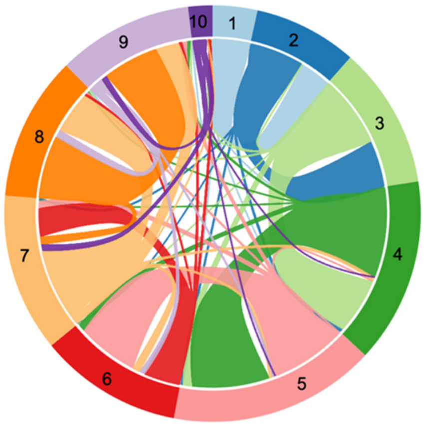

Fig. 9: Learning routes in guided face-to-face teaching.

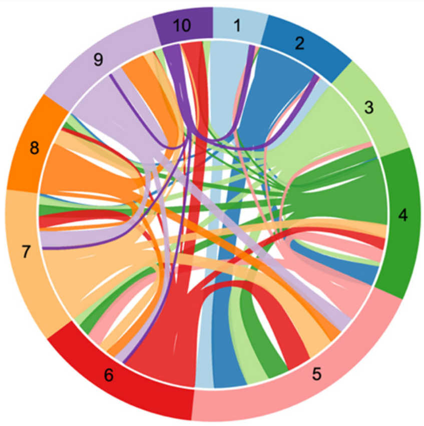

Fig. 10: Learning routes during self-study.

Comparing the three chord diagrams with each other, the following similarities or distinctions in the three groups are noticeable.

Common to all groups is the fairly uniform distribution of processing time among the individual learning units. Thus, all students spend the main part of their time processing the basic knowledge unit (segment no. 5) and working on the *task sets* (segments no. 6-9).

However, the jumping behavior of the students in the three groups is clearly different.

In the guided face-to-face teaching group (Fig. 9), the students predominantly followed the instructions of the lecturer. Here, the chords mostly end at the next higher learning unit / task set. In the guided face-to-face teaching group, there are few jumps from the tasks back to the basic knowledge section (unit 5).

In the guided online teaching group (Fig. 8), as in the guided face-to-face teaching group, jumps to the next higher learning unit can be seen. However, the relative frequency of these jumps is smaller than in the guided face-to-face group. Instead, the guided online teaching group also shows a tendency for backward jumps, especially between the tasks and the basic knowledge sections. As an example, the purple-colored chord from learning unit 9 back to unit 5 in Fig. 8 shows this particularly clearly.

In the self-study group (Fig. 10), forward and backward jumps balanced out. The jumping behavior looks rather chaotic here. It is striking that the units *basic knowledge section* (No. 5) and *task sets* (No. 6-9) are chosen very early in the learning process by the students. Especially from unit 3 (functions of transistors) quite a few jumps (light green chords) go to the different tasks instead of to the next higher unit.

12. Discussion

The evaluation should answer the question whether learning with interactive tasks and getting to know a tool for creating these tasks in different teaching formats differs in terms of learning processes and learning success and whether the own learning with interactive tasks and getting to know the tool positively influence the perceived acceptance and relevance.

In summary, the evaluation shows a significant increase in acceptance and relevance of the interactive tasks and the H5P tool after learning with these tasks and becoming familiar with the tool. This positive development can be seen in all groups, so that there are no differences here with regard to relevance and rather unimportant differences with regard to acceptance between the three groups. This result is not surprising overall, since experience with a technology influences the intention to use it directly and indirectly via perceived usefulness [e.g., 22].

The results show an increase in professional knowledge. The TPACK can be another factor for the acceptance towards a technology, especially if the users (here prospective teachers) are still inexperienced [22]. The effect strength is small, which is not surprising after learning with one application example and only a short tool description. There are also small differences between the groups, but these are of little importance and presumably disappear after the second session, when the tool is used in an active way.

Regarding learning successes and processing times, the results do not show any significant differences between the guided online and the guided face-to-face courses. However, here the self-study group performs significantly worse on both measures. Since both active learning time and guidance influence learning success [23], the differences here seem particularly noteworthy. The question of the causes of the differences in processing time and learning success between the self-study group on the one hand and the two guided groups on the other hand cannot be answered finally. However, assumptions can be made. It cannot generally be assumed that a long processing time is equivalent to a longer (cognitively) active processing. One could also let the time pass and do nothing. On the other hand, a short processing time does not allow an in-depth learning. The results show a positive correlation of high effect size between processing time and learning success, which suggests that an adequate processing time is a necessary condition for learning success (although it is not sufficient). One reason for the low processing time in the self-study group could be due to the lack of guidance through the learning path. To answer this question, one would need to test a full experimental design. This means that in addition to the groups mentioned above, another group would have to work with the learning path in presence but without guidance. Another reason for the lower performance of the self-study group could be the playful format. Especially in the self-study group, there might be a temptation to be as fast as possible rather than as thorough as possible. In the guided groups, the tight guidance makes it less possible to hurry through. A third reason could be a cost-benefit consideration by the students. Comparable behavior is also shown in another study [e.g., 18]. In the self-study group, the students have the freedom to take their learning into their own hands and to assess for themselves whether the expected return for the effort to be expended seems worthwhile to them or not.

13. Limits and outlook

The evaluation is limited to aspects of acceptance development with a focus on professional knowledge and perception of relevance. Questions on affective components of learning or on design criteria of tasks are not presented.

The measurement of professional knowledge is based on the established procedure for measuring acceptance and TPACK. It is therefore carried out by self-assessment. Without further data material, it would remain open which competencies have developed. In this study, however, the results of the tasks in the learning process are also available, so there are further indications of the competencies.

The teaching format varies corona-dependently and not systematically, so both the control of confounding variables is limited and the group design is incomplete. Therefore, no causalities can be derived from the evaluation results. Their use rather lies in generating hypotheses for an empirical study on the one hand and in optimizing the learning material in the sense of a design-based research approach on the other hand.

The sample is neither representative nor completely homogeneous. In addition, the small sample size sets limits to the analyses.

Further studies and interviews should explore the differences in learning times and their causes. In doing so, these results can provide cues for possible research questions that can then be systematically addressed empirically in a full experimental design. In addition, with new technical possibilities in the field of AI, it would be interesting to identify patterns in learning routes that then allow instantaneous predictions of learning outcome in the learning process.

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