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BEST PRACTICE

# Learning and Teaching Astronomy with Digital Tools promotes Preservice Physics Teachers' digital Competencies

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## Abstract

In this paper, we study the experiences of preservice physics teachers when they are asked to use modern digital tools within learner-centered astronomy education. Since digital tools are of particular importance in astronomy, this context provides an authentic setting for testing the effects of both, learning and teaching, for digital competence. The project was carried out as a highly-modified tutorial accompanying an introductory astronomy lecture with 20 M.Ed. physics students. The preservice teachers were given an opportunity to apply the techniques learned within day-long projects carried out with visiting school classes. A significant increase in digital competence, assessed by a TPACK self-assessment, was observed after the 13-week tutorial. From interviews, twelve main strengths (e.g. familiarity with digital tools) and two main weaknesses (e.g. preparation for exam) of the course could be identified. The developed astronomy course concept can be easily adapted to conditions of other universities and the digital tools developed or used can also be adopted in high school classes.

**Keywords**: digital tools; astronomy tutorial; TPACK; attitude; course evaluation

## 1 Introduction

Life in the 21st century is characterized by increasing digitization, and the constant evolution in new technology also affects the way we learn. It is therefore natural that digital competence has been declared as one of the eight key competencies for lifelong learning by the European Union (Council of the European Union, 2018). To help pupils achieve digital skills to their full potential, teachers need some expert knowledge in order to incorporate digital media and digital tools into their instruction. Unfortunately, studies performed in Germany have concluded that especially today's preservice teachers are not necessarily digitally affine as expected from "Digital Natives" (Persike and Friedrich, 2016; Schmid et al., 2017). This article describes a concrete attempt at promoting the digital competencies of preservice physics teachers during their university education in Göttingen in order to prepare them for successful digitally-based physics teaching. For this purpose, a new concept for the tutorial of an introductory course in astronomy for physics teacher students was developed and evaluated. In astrophysics, digital tools like computer simulations play a special role, since many processes cannot be studied in the laboratory. Accordingly, learning astronomical content using digital tools can provide a highly authentic and modern opportunity for preservice teachers to expand their professional knowledge about *learning* with digital media. Therefore, we have integrated various digital technologies into a tutorial that runs in parallel to the astronomy lecture. The activities include an explicit didactic framework, the details of which are described in this article. At the end of the tutorial, we studied the development of the students' competencies, their attitude towards learning with digital media, and included an exploratory evaluation of the developed course.

# 2 Background

To understand how the project was designed and carried out, it is useful to describe the astronomy education situation in Germany and to reflect on what potential astronomy education has for learning and teaching with digital tools. Therefore, the didactic foundation behind the use of digital tools in the classroom is also discussed. A section follows on the existing approaches for promoting the digital competencies of (preservice) teachers. Finally, the formal aims of this research are outlined.

## 2.1 Astronomy Education

The educational standards for German high schools acknowledge that astronomy can serve to deepen and broaden regular physics classes as well as illustrate the diversity of physics and address its current developments (KMK, 2020). However, astronomy is not an obligatory but an optional part of the curriculum in most German high schools other than the topics briefly mentioned in physics classes. Therefore, it is not surprising that only a few German universities teach astronomy to their preservice physics teachers. At the same time, there are many arguments in favour of teaching astronomy at schools or universities, given the obvious potential for learners. Percy (2009) lists many of these reasons, summarized here: Astronomy is socially relevant and an essential part of historical and modern science; dealing with astronomy is useful and competence-enhancing for learners in many ways. In addition, the German and Austrian ROSE survey reports a great interest among students of both genders at the end of lower secondary level in astronomy and the universe (Elster, 2007). Since astronomy is based on classical concepts of physics (Percy, 2009), links to astronomy can and should be established on the basis of the physics curriculum. Furthermore, learning and teaching astronomy should foster working with modern technology, since its methodological approach differs from that of classical physics: the raw form of modern astronomical information is generally a digital image that can often be processed and studied in a school classroom (Hessman and Modrow, 2006) and digital simulations and models have a much greater importance than direct lab experiments.

***The status quo at the University of Göttingen***

Given the expected potential of astronomy education, all Master of Education (M.Ed.) physics students at our university take the obligatory module *Introduction to Astrophysics*, consisting of a lecture (twice a week) and a tutorial (once a week). The lecture covers basic topics such as astronomical instruments, the Solar System, exoplanets, stellar structure and evolution, astrobiology, galaxies, and cosmology. When the special course for M.Ed. students was created, the tutorial was changed in an attempt to provide related activities that could be used in real-life school situations: these activities included programming simulations with `Snap!` (Harvey and Mönig, 2021) and `GeoGebra` (Hohenwarter and collaborators, 2021) and reducing photometric observations with `ImageJ` (Rasband and collaborators, 2021; Hessman and Modrow, 2006) or `AstroImageJ` (Collins et al., 2017). In order to place the tutorial in a more explicit didactic and medial context, and to measure the efficacy of this approach, the tutorial was further developed with the intent of promoting and testing the participating students' digital competencies.

## 2.2 Learning with digital tools

The term *digital tools* refers to software that is used with a computer or digital device and facilitates daily routine and tasks in general and teaching-learning processes in an educational context. Hillmayr et al. (2020) found in their meta-analysis that using digital tools influences student learning outcomes positively with a medium effect and that it has a small positive effect on their attitude towards the taught subject. Moreover they report that teaching and learning with digital tools can increase learners motivation and so have an influence not only on cognitive, but also on affective learning outcomes. If the digital tool ensures that learning is not *from* but *with* digital media, it is even a *cognitive* digital tool (Jonassen, 1995). Such tools (e.g. spreadsheets, computer simulations, databases) support or take over routine tasks and can thus relieve learners cognitively so that they can focus on the actual subject matter (Van Joolingen, 1999). The *Cognitive Theory of Multimedia Learning* by Mayer (2001) explains these beneficial impacts of learning with digital tools, among other aspects, with the assumption that learners actively engage with a learning content and so act as active processors who construct coherent mental representations. Thus, if computer programs are used as cognitive learning tools rather than as a directive instructional medium, this should enable learners to actively construct knowledge themselves instead of reproducing information (Jonassen, 1994). Digital tools are also suited for open formats like discovery learning, where learners actively engage with the subject matter and thus, compared to traditional formats, structure their knowledge better (Van Joolingen, 1999). Overall, it is not recommended to use a digital tool merely as an end in itself but rather in combination with conventional methods (Hillmayr et al., 2020).

***Simulation-based learning***

Because computer simulations are of particular importance in astronomy and exemplary for enhancing learning with digital tools, simulation-based learning needs to be covered in more detail. Educational simulations are based on models and represent a reduced form of reality, which decreases the learners' cognitive load (De Jong, 2011). Compared to other learning materials, simulations can represent expert-like models more explicitly and address common misconceptions by making invisible (physical) principles visible in order to support learning and the building of mental models (Wieman et al., 2010). Usually, educational simulations stand out due to their high level of interactivity (Finkelstein et al., 2005) and within the context of discovery learning, learning environments can be designed in a particularly learner-centered way (De Jong, 2011). One strength of simulation is that they can be used when a laboratory experiment is not possible for various reasons (e.g. impractical, too expensive, forbidden). In contrast to real experiments, simulations contain implicit constraints on the learning process, implicitly guiding students in their individual engagement with the simulation. Consequently, the scope of action remains within a range that productively promotes discovery learning and makes learners' discovery process more authentic and productive (Podolefsky et al., 2010). In astronomy in particular, simulations allow an easy manipulation of variables that cannot be varied in reality (e.g. mass of celestial objects) (Wieman et al., 2010). In physics education, simulations are used especially for qualitative clarification of concepts and solutions (e.g. gravity). By working with educational simulations, learners may encounter questions and methods of inquiry that are relevant to scientific research (Podolefsky et al., 2010). Learning astronomy with simulations consequently creates an authentic and realistic learning environment that addresses modern methods. The precondition is that teachers have adequate competencies (Hillmayr et al., 2020; Rutten et al., 2012).

### 2.3 Promoting preservice teachers' technological proficiency

Teachers need expert knowledge and proper skills when teaching with digital tools in order to plan and implement digital based education. This is why various special in-service teacher training programs have been developed with concrete concepts for the promotion of digital competencies. In astronomy education, one of the classic examples of this type of curriculum-based training was the *Hands-On Universe* project developed by the University of California at Berkeley (Boër et al., 2001), which, in turn, has spun off a wide variety of similar curricula. Important for such professional development programs is that participants not only learn how to use technology, but also to deal with that use in a pedagogical context and in connection with the subject content (Angeli et al., 2015; Koehler and Mishra, 2005). Researchers therefore often rely on so-called *Technological Pedagogical Content Knowledge* (see section 3.1), a framework for integrating technology into a classroom setting (Mishra and Koehler, 2006). Thus, the successful promotion of teachers' technology proficiency requires making it clear that this is more than merely finding and applying useful digital tools. Koehler and Mishra (2005) therefore utilize the *Learning by Design* approach during which teachers practice problem-solving by developing digital based solutions to authentic problems with an explicit pedagogical and topical reference. With reference to astronomy, teaching high school students about stellar evolution, for example, could be posed as an authentic problem being solved by implementing technology. So far, no example can be found in the literature that explicitly links such a teacher training to astronomy, although this science seems to be very suitable for this purpose (see section 2.1).

### 2.4 Research aims

Building on the previous explanations, we have developed a new concept to integrate digital tools systematically in an astronomy tutorial for preservice physics teachers. To go one step beyond simply accumulating knowledge about how to use these tools, the students not only had to learn astronomy with these tools, but also engage with them from a didactic perspective. The new concept therefore includes linking astronomical content to the task of creating or using digital tools to facilitate learner-centered forms of work. The students are asked to engage extensively with the digital tools by themselves while learning astronomy and then to apply the same techniques by teaching astronomy with digital tools to high school students. Developing this new concept thus goes hand-in-hand with the goal of promoting digital competencies of preservice teachers and contributing to their professionalization. A multi-method approach was used to quantitatively assess the development of students' digital competencies and attitude towards learning with digital tools over time as well as to qualitatively evaluate the tutorial.

## 3 Theory

In this section, a framework for the digital competencies of (preservice) teachers is presented and the importance of attitude for an actual use of digital media is described. Both theories correspond to the underlying theoretical frameworks used in the study and influence the extent to which a (preservice) teacher successfully integrates technology in the classroom.

### 3.1 Digital Competencies

Different frameworks are used to operationalize the description of teachers digital competencies. Mishra and Koehler (2006) propose a framework for technology-based teacher knowledge that has already been adapted internationally in educational research with reference to technology (Gur et al., 2015). It is an extension of *Pedagogical Content Knowledge* (PCK), a theoretical description of teacher professional knowledge defined by Shulman (1986), which combines *Content Knowledge* (CK) and *Pedagogical Knowledge* (PK) as the essential knowledge for teachers and defines the overlap of these two as PCK. CK refers to the knowledge in the subject being learned or taught, e.g. astronomy. PK includes the understanding of methods, theories and processes of learning and teaching, e.g. classroom management (Mishra and Koehler, 2006). Analyzing learning processes not in general but related to a specific subject content is part of the PCK and that means, inter alia, knowing the contents' useful representations and explanations as well as the learners' prior knowledge and misconceptions (Shulman, 1986).

In the case where technologies such as word processors, spreadsheets, and—for our purposes especially important—programming environments are integrated into teaching activities, the teachers' *Technology Knowledge* (TK) becomes relevant and further overlaps arise: *Technological Pedagogical Knowledge* (TPK), *Technological Content Knowledge* (TCK) and *Technological Pedagogical and Content Knowledge* (TPACK) (Mishra and Koehler, 2006). A deep understanding of the close interaction between content and technology, e.g. between astronomy and simulation, as well as the resulting opportunity to influence subject-matter learning through technology, is part of the TCK. Having TPK at your disposal means knowing the impact of technology on the way we teach and learn, including knowledge about the pedagogical constraints and applicability of different technological tools. As a total overlap, TPACK represents the teachers' central skills for using technology in teaching-learning processes. As shown in Figure 1, it addresses the complex interplay between subject content, pedagogy, technology and context (teaching-learning situation) (Koehler and Mishra, 2009).

The TPACK framework can be used for theory-based curricu-

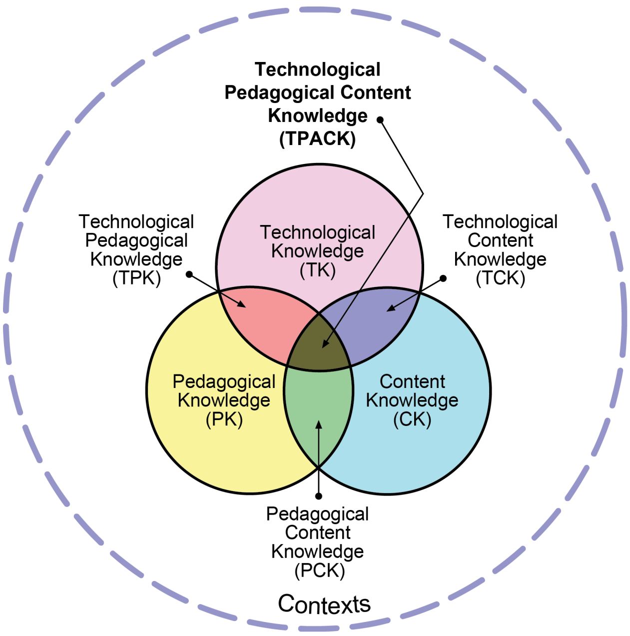


**Figure 1.** The theoretical TPACK framework (reproduced by permission of the publisher, 2012, by `http://tpack.org`).

lum development in teacher education by identifying what professional knowledge is needed for successful teaching with technology (Mishra and Koehler, 2006). Furthermore, Schmidt et al. (2009) developed an instrument for self-assessment of TPACK to check and support the (preservice) teachers' competence development.

## 3.2 Attitude towards learning with Digital Media

Having the appropriate digital competencies is not the only requirement for successful teaching with technology. According to the *Theory of Planned Behavior* (TPB) (Ajzen, 1991), teachers' attitude also affects using digital media in classroom. The TPB illustrated in Figure 2 presents a person's actual behavior as directly influenced by his or her intention to perform this behavior; the strength of intention affects the probability of an individual's performance. Intention is, in turn, determined by three independent cognitive factors: (i) *attitude towards the behavior* (to what degree do I rate the behavior as favorable?); (ii) *subjective norm* (to what extent does my social environment expect this action to be performed?); and (iii) *perceived behavioral control* (what is the perceived difficulty of the behavior?). With factor (iii), one's own competencies become relevant. They function as a basis for an individual difficulty estimation. Moreover, the TPB posits salient beliefs (*behavioral, normative, control*) as the basis for predicting and even explaining behavior (Ajzen, 1991).

In summary, (i) the more favorable a teacher sees learning with digital media, (ii) the greater his or her perceived social pressure to use digital media in classroom, and (iii) the greater a teacher feels in control of using digital media in classroom, the more likely a teacher is to actually use digital media in classroom. Thus, a teacher's digital competencies as theoretically described by the TPACK framework (section 3.1) can be linked to the TPB (perceived behavioral control) here.

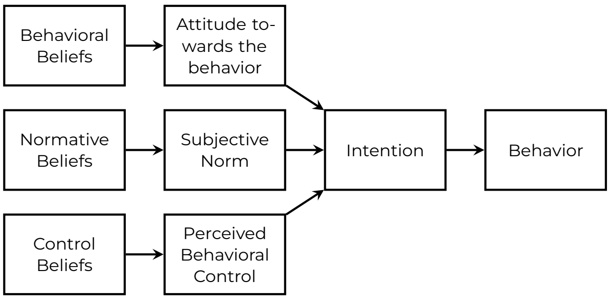


**Figure 2.** Theory of Planned Behavior (adapted from Ajzen (1991)).

The TPB is the basis for many educational research approaches, in particular in the area of using technology in classroom. This framework is used, for example, to predict (preservice) teachers' intention to use digital learning materials or educational technology (Kreijns et al., 2013; Lee et al., 2010; Valtonen et al., 2015), to investigate the influence of preservice science teachers' experience with digital media on their attitude towards using digital media in their teaching (Vogelsang et al., 2019), as well as to model their intentions to use it for teaching and learning (Valtonen et al., 2015).

# 4 Methods

The research aim introduced in section 2.4 was to investigate the preservice physics teachers' digital competencies and attitude towards learning with digital tools in the context of the astronomy tutorial developed. In addition to measuring the tutorial's impact, we wanted to optimize this approach based on an evaluation study. From these purposes, the following research questions were derived:

**Q1** *How do the students' TPACK self-assessments of the technology-related components change during the course?*
Students are expected to assess their TK, TCK, TPK and TPACK higher as the tutorial progresses.

**Q2** *How does the students' attitude towards learning with digital media change after participating in the course?*
It is expected that students' attitude will become more positive during the course of the tutorial and they are expected to be generally positive about learning with digital media thereafter.

**Q3** *How do the students evaluate the course?*
No expectations are expressed in this regard, as an exploratory survey is planned.

To answer these questions, three questionnaires were used at three points of time ("pre", "mid", and "post"), and semi-structured interviews were held at one point of time ("post") (see Fig. 3). One questionnaire ("pre") was given in the very first session, the second one was used during halfway through ("mid"), and the last one was used afterwards ("post")—a within-subject design without any control group. The data from this multi-method approach will be quantitatively analyzed to answer the first two questions and qualitatively analyzed to tentatively answer the third question. The students' attitude was examined in all three surveys to determine the current states in each case. The technology-related scales to TPACK-self-assessment were examined in a retrospective "pre"-"post"-design to prevent a response shift bias (change of individual reference) due to an increase in competence (Bhanji et al., 2012). At midtest, students assessed their TPACK a) retrospectively for an earlier time (tutorial start) and b) for now (halfway through). At posttest, they also assessed it a) retrospectively for tutorial start and c) for now (tutorial end). Thus, TPACK scales were used in the second and third survey only. In addition, the "post" questionnaire included a manipulation check to compensate for the design-related lack of a control and intervention group. Furthermore, items were used in the "post" to ask for feedback on the digital tools used and the didactic basis provided in order to extend the evaluation.

## 4.1 Questionnaires

The three questionnaires each took between five and fifteen minutes to complete. Building on the theory presented in section 3, the constructs *TK, TCK, TPK, TPACK* as well as the *attitude* towards learning with digital media were studied (Table 1). The four TPACK-scales were adapted from Schmidt et al. (2009), who developed a valid and reliable instrument directly based on the TPACK framework by Mishra and Koehler (2006) in order to investigate preservice teachers' TPACK self-assessment. The content-independent TK and TPK scales were adopted unchanged. Schmidt et al. (2009) distinguish four types of CK

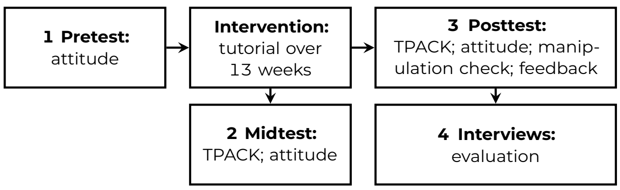


**Figure 3.** Research desing of the multi-method approach. The technology-related TPACK is examined retrospectively.

**Table 1.** Overview of scales used.

| Scale | Items | Example | $\alpha$ |
|---|---|---|---|
| TK | 7 | I have the technical skills I need to use the technology. | .87 |
| TCK | 1 | I know about technologies that I can use for understanding and doing physics. | – |
| TPK | 5 | I can choose technologies that enhance students' learning for a lesson. | .70 |
| TPACK | 5 | I can teach lessons that appropriately combine physics, technologies and teaching approaches. | .86 |
| Attitude | 8 | Digital media promotes greater student activation. | .55 |

The listed Cronbach's alpha coefficient for internal consistency reliability corresponds to the mean value from all measurement time points.

(literacy, mathematics, social studies, science). Their original items *"I can teach lessons that appropriately combine [each type of CK], technologies, and teaching approaches"* (TPACK scale) and *"I know about technologies that I can use for understanding and doing [each type of CK]"* (TCK scale) were rewritten with "physics" (s. tabular 1). Both original scales were thus reduced by three items each. No further changes were done and the German translation was adapted from Endberg (2019). The scale for attitude was adapted without change from Vogelsang et al. (2019) who developed and used it in a survey of more than 600 science teacher students in Germany. Their scale contains items like *"Learning with digital media is an efficient form of learning."* Table 1 contains sample items for each scale used.

All items were recorded using a six-point Likert scale (*1—do not agree at all* up to *6—fully agree*). The questionnaires were conducted online and the statistical analyses were performed with the free software PSPP (Free Software Foundation, 2021). Each person gave a personal code for pseudonymization so that data from all three measurements could be linked to a person. The data from all different measurement time points were compared using a paired t-test. All $p^*$-values calculated for significance were obtained as a function of the number of statistical comparisons via a Bonferroni correction. Moreover, effect sizes (Cohen's *d*) were calculated for the statistical differences found.

As a dimension of internal consistency reliability, Cronbach's alpha was determined for each scale consisting of more than one item (Table 1). All TPACK scales show good or acceptable values of the coefficient ($\alpha \geq .70$). However, the attitude-scale results in a poor internal consistency ($\alpha = .55$). Here, no item can be clearly identified whose removal would increase the value in an acceptable consistency. The reason could be the small and homogeneous sample, composed of 20 physics teachers student (M.Ed.). That is why we additionally used the scale in a survey with 73 teachers students (M.Ed.) from different disciplines. Here, attitude scale shows a good internal consistency ($\alpha = .86$). Vogelsang et al. (2019) were also able to find a good internal consistency ($\alpha = .83$) for this scale in their research study. For this reason, the scale is not discarded as a measurement instrument but the interpretation of the results explicitly takes into account that low reliability reduces its strength.

#### *Additional items*

In addition to the TPACK and attitude scales, further items on *Manipulation Check* and *Feedback* were used in the "post" as well as items for gathering the students' demographic background in the "pre". Thus, the scales listed in Table 1 are supplemented by nine items for manipulation check: *"For successful participation and task completion, the tutorial required i) knowledge about subject content, ii) knowledge about didactic content, iii-ix) various areas of digital competencies."* These items were self-formulated, whereby the digital competencies (7 Items, $\alpha = .83$) correspond to the areas of the competency framework according to Becker et al. (2020): documentation, presentation, communication, research, measurement, data, simulation. To compensate for the missing control group, these items are used to compare the astronomy tutorial as an intervention with traditional physics tutorials. For this purpose, these items were used in a questionnaire, which was filled out by ten preservice physics teachers from the Bachelor's program at the University of Göttingen. A t-test for independent samples was done for statistical analysis. The second extension of the "post" questionnaire was made by including four self-formulated items asking for feedback on the digital tools and the didactic phases: *"The digital tools used were a) helpful for learning successfully, b) matched to the subject content." "The didactic phases were c) helpful for me as a intending teacher because it gave me a more comprehensive engagement with didactic, d) matched to the subject content."* Both the manipulation check and feedback were recorded using the same six-point Likert scale as mentioned above.

### 4.2 Interviews

Semi-structured interviews using four guiding questions were conducted in the qualitative research part. Based on the research interest, possible interview questions were collected, reviewed, and finally sorted into categories. Then, a guiding question was formulated for each category to motivate the subjects reporting openly and freely (Niebert and Gropengießer, 2014): *(1) How did you experience the tutorial last semester? (2) Please tell me about your previous experience with physics tutorials. (3) To what extent did participating in the tutorial have an impact on your learning process? (4) What do you think about using digital tools in classroom as a teacher in future*? Two final questions were also aimed at the overall evaluation of the tutorial and specific suggestions for improvement.

The interviews were recorded, transcribed in anonymized form and then analyzed using qualitative content analysis according to Mayring (2014). Using a deductive-inductive approach for course evaluation as proposed by Mayring (2019), qualitative content analysis was used to investigate how satisfied the participants were with the course (deductive) and what were the main perceived strengths and weaknesses of the course (inductive). The participants' satisfaction was examined by five deductive ordinal categories ranging from *very satisfied* to *very dissatisfied*. The categories' definition refers to *Multiple Discrepancies Theory* (Michalos, 1985) and accordingly sees satisfaction as a cognitive process in which previous experiences or ideals serve as a benchmark to assess a current situation (Mayring, 2019). To code these deductive categories, the entire interview was considered as the unit of analysis. If, for example, no negative aspects but praise and approval regarding the course were expressed and the question about the overall impression was clearly positive, then the interview was assigned the category *very satisfactory*. If one of these points did not apply, then it is *satisfactory* and so on (Mayring, 2019). In an inductive category formation, moreover, subcategories for the deductive main categories *Strength* and *Weakness* were obtained by subsumption. A statement was coded as strong, if the aspect was clearly evaluated as positive, no negative arguments or examples were expressed, a neutral attitude was not assigned to this category, the argumentation referred to more than one situation and the arguments were not relativized or invalidated by own statements directly afterwards. This applied accordingly vice versa for weaknesses.

### 4.3 Intervention

The astronomy tutorial took place on 13 sessions in conjunction with lectures and lasted 90 minutes weekly. A team-teaching approach was used by having one astronomy expert tutor (an astrophysics graduate student) and one physics education expert tutor (R.L). Each expert was responsible for teaching his or her special field, either astronomical content (Fig. 4: left column) or the didactic basis content (Fig. 4: Roman numerals). The weekly homework assignments (Fig. 4: right column) had both didactic (yellow boxes) and astronomical emphases (gray boxes), so that the correction and discussion was divided between the two tutors. In each lesson, students actively engaged with the lecture content using an appropriate digital tool to support their learning process. Such learning phases are symbolized by gray boxes in Figure 4 because they can be flexibly adapted to alternative lecture content. One lecture content had to serve as the topic for the students' practical experience with high school students: we chose the search for exoplanets. The students got instructional support from assignment sheets, working in groups of two or three, and direct support by the tutors. Thus, the students engaged actively with astronomical issues not only while doing their homework—the normal mode in tutorials—but also during the tutorial session itself.

The astronomical contents addressed and the digital tools used in our tutorial are listed in Table 2. A search for freely available tools revealed that these only cover a small number of the chosen topics and their quality, function or suitability is often too low. Therefore, a large part of the tools used were developed in-house (Table 2) and thus optimized to user and content focus. A key advantage of using tools such as `Snap!` or `GeoGebra` is that students can create their own simulations and individually revise existing simulations even with little programming skills. A total of 13 topics were covered in the tutorial, distributed across the boxes in Figure 4, some of which were assigned to more than one cell due to their complexity. Various free and accessible software packages were used to achieve different goals, so that students are exposed to a wide range of digitally-based learning processes. These learning goals are also described in Table 2.

The tutorial's focus on astronomical content was complemented by elements that promoted didactic competencies regarding learning and teaching with digital tools. Dealing with the didactic basis was done in four phases, as shown in Figure 4. The first phase was an introduction to the relevant theory and literature in order to create the necessary background knowledge. In four designated sessions, the didactic-expert tutor first gave a short presentation, followed by suggestions and instructions for discussing the new topics within the framework of the astronomical content and the functionality/handling of the digital tool. For example, the students first learned criteria for evaluating a simulation before using them to analyze a Kepler simulation (Snap!) they had created before. As another example, the students formulated instructions for learners who might use their telescope optics simulation (GeoGebra), based on simulation-learning concepts and the role of instructional support. For the second phase, didactic inputs were no longer needed and students were instead supported in their lesson-planning via personal feedback on their homework. Here, integrating technologies into an astronomy lesson was mandatory. Next, the students taught pupils of cooperating high schools in town. To support each other for these new challenges, the students planned and tested a lesson in astronomy in groups of two or three. This allowed them to observe each other teaching astronomy with digital tools and then to write a case study to reflect and analyze their practical experiences (fourth phase). At the beginning of each session, students briefly shared their experience, discussed pupils' possible misconceptions in astronomy, and reflected on and discussed their own behavior.

Due to the current pandemic, the tutorial was held online via a video conferencing platform and the same was true for the astronomy lessons with the high school students. Since an exam in presence was not possible as originally planned, the final examination format for lecture and tutorial was changed to a written assignment.

## 5 Data Description

Qualitative and quantitative data collection was needed to answer the research questions (section 4). The participants therefore directly received access to each questionnaire by a shared link and filled it in immediately. Participation was voluntary and anonymous. The data were collected digitally and stored as well as analyzed exclusively for these research purposes. All participants in the tutorial were informed about the plan to conduct interviews and volunteered to do so. For quality control of the qualitative data, we determined Cohen's kappa as a statistical measure of interrater reliability. A second rater additionally coded half of the transcripts. There was complete agreement on the satisfaction rating ($\kappa = 1$). Moreover, there was an almost perfect agreement in the rating of strengths and weaknesses ($\kappa = 0.82$) and after discussing the rating the value increased to $\kappa = 0.89$.

**Table 2.** The astronomical topics, the digital tools that were used, and the digital competencies addressed.

| | Topic | Tool | Competence |
|---|---|---|---|
| (a) | Astronomical coordinates | Stellarium | Simulate an astronomical observation |
| (b) | Telescope optics | GeoGebra | Create a simulation |
| (c) | Planetary orbits and Kepler's laws | Snap! | Create a simulation, compare simulations |
| (d) | Moons of Jupiter | Stellarium, Spreadsheet | Take and analyze simulated data |
| (e) | Exoplanet radial velocity method | GeoGebra-Simulation[1] | Simulation-based learning (self-learning) |
| (f) | Exoplanet transit method | Snap!-Simulation[1] | Simulation-based learning (self-learning) |
| (g) | Blackbody spectrum | Snap!-, Python-Simulation[1] | Simulation-based learning (self-learning) |
| (h) | Stellar spectra | SDSS Database | Research and structure information |
| (i) | Hertzsprung-Russell diagram | Simulation | Use of a digital dynamic representation |
| (j) | Variable stars | Spreadsheet | Digital data processing |
| (k) | Cosmic distance ladder | (Astro)ImageJ | Digital data collection and processing |
| (l) | Parallax | Snap!-Simulation[1] | Use of a digital dynamic representation |
| (m) | Cosmology (Hubble's law) | Snap!-Simulation[1] | Compare models (digital visualization) |

[1]The materials were developed by ourselves and can be made available upon request.

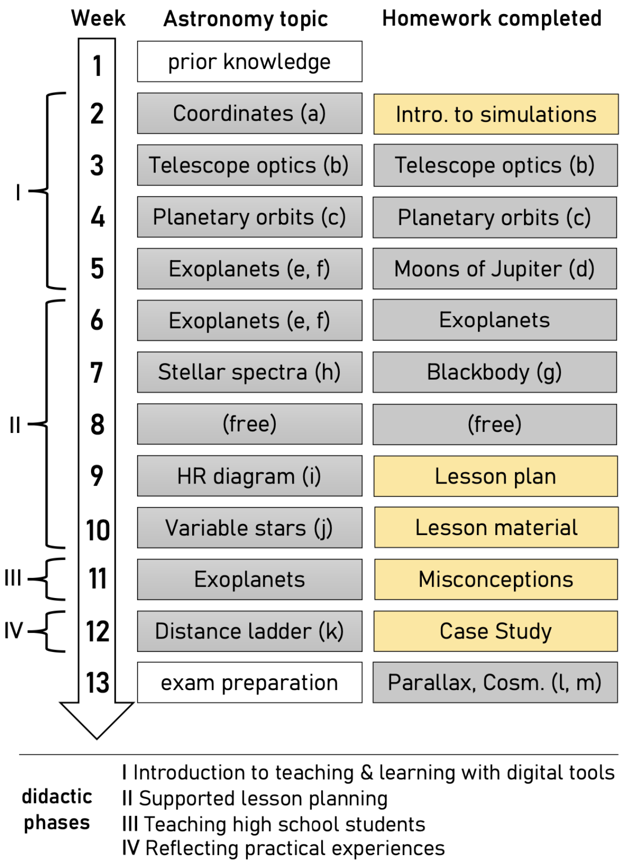


**Figure 4.** An overview of the astronomy tutorial's structure consisting of a session's astronomy topic (left column) and homework assignments (right column). Sessions of 13 weeks are divided into four didactic phases (Roman numerals) concerning learning and teaching with digital tools. Gray boxes indicate space for an adaptation to lecture content and digital tools (the given letters can be found in Table 2 and provide information about the tools used). Yellow boxes indicate a didactic focus. The topic of exoplanets was used as a lesson content example and is therefore the most frequently addressed. Session 8 did not happen due to the Christmas holidays.

## 5.1 Sample

The developed concept and the accompanying research were piloted with 20 physics teacher students (16 male, four female) at the University of Göttingen (Germany) in the winter semester 2020/2021. They had a mean age of 25.7 ($SD$ = 3.39). The sample is composed of the cohort of 15 students taking the obligatory module for the first time and five students who took the module last year but did not take the exam. On average, the participants were in their second M.Ed. semester. 16 out of 20 students were present at the weekly sessions ($SD$=2.48) and there was no attendance requirement. The first questionnaire ("pre") was completed by 20, the second one ("mid") by 12 and the last one ("post") by 16 students; the over all research response rate was 80%. About two thirds of the students indicated no prior experiences in teaching with simulations as digital tools. For spreadsheets it was even more than 80% without any prior experience. Six volunteers participated in the interviews so here the response rate (30%) was lower than for the questionnaires.

# 6 Analyses

## 6.1 TPACK self-assessment

The students' retrospective technology-related TPACK self-assessment based on a six-point Likert scale is shown in Figure

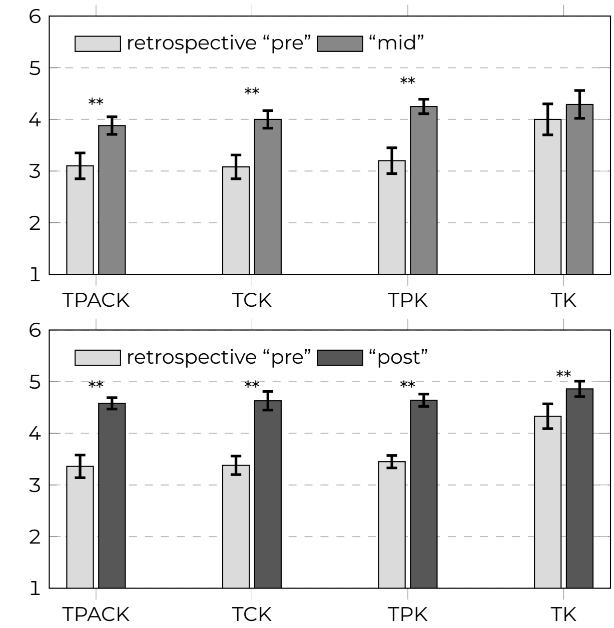


**Figure 5.** Results on TPACK self-assessment in retrospective "pre"-"mid" comparison (top) and retrospective "pre"-"post" comparison (bottom). At "mid" and "post", the respective current as well as retrospective data for the time before the intervention ("pre") are shown. The retrospective "pre" was collected separately at both test times ("mid", "post"). Error bars indicate the standard errors of the mean values.

5. Because of the retrospective "pre"-"post" approach (section 4), the four TPACK scales were queried both times - "mid" and "post". First, the measurement during the intervention ("mid") is taken into account (Fig. 5, top): based on the scales used, the students retrospectively rate their TPACK with a value of 3.10 ($SD$=0.88), TCK by 3.08 ($SD$=0.79) and TPK by 3.20 ($SD$=0.85) as rather low for the time before their participation, whereas their retrospective TK with a value of 4.00 ($SD$=1.03) is rather high. During the tutorial, they rate their TPACK ($M$=3.88, $SD$=0.59), TCK ($M$=4.00, $SD$=0.60), TPK ($M$=4.25, $SD$=0.47) and TK ($M$=4.29, $SD$=0.92) with an overall rather high scale level. Thus, the TPACK scale is significantly higher after seven weeks of participating in the tutorial ($t(11)=5.42$, $p^* < 0.01$, $d=1.57$). This is equally evident for TCK scale ($t(11) = 4.75$, $p^* = 0.01$, $d = 1.37$) and TPK scale ($t(11)=6.65$, $p^* < 0.01$, $d=1.92$), although the self-assessed TK scale shows no significant difference ($t(11)=5.42$, $p^* > 0.05$) after participating for the first seven weeks.

In the measurement after the end of the tutorial ("post"; fig. 5, bottom), the students retrospectively self-assess their previous TPACK ($M$=3.36, $SD$=0.90), TCK ($M$=3.38, $SD$=1.26) as well as TPK ($M$ = 3.45, $SD$ = 0.83) as rather low and their TK ($M$ = 4.33, $SD$ = 0.96) as rather high. The students rate their TPACK at the tutorials end as high ($M$=4.58, $SD$=0.45) and significantly higher than before ($t(15)=6.21$, $p^* < 0.01$, $d=1.92$). Similar to the "mid", the students' self-assessed TCK ($M$=4.63, $SD$=0.72) and TPK ($M$=4.64, $SD$=0.47) turn out to be rather high in general. TCK ($t(15) = 5.00$, $p^* < 0.01$, $d = 1.25$) and TPK ( $t(15) = 6.46$, $p^* < 0.01$, $d = 1.62$) are significantly higher than retrospective scales with strong effects. Furthermore, after participating in the astronomy tutorial, students assess their TK significantly higher with a strong effect size ($t(15)=4.67$, $p^* < 0.01$, $d=1.17$). A comparison of self-assessment between "mid" and "post" is not meaningful here because of the retrospective "pre"-"post"-design.

## 6.2 Attitude

Looking at the scale used for participants' attitude towards learning with digital media, it can be said that the students are basically positive about it before ($M$ = 4.56, $SD$ = 0.48), during ($M$ = 4.64, $SD$ = 0.38) and at the end of the tutorial ($M$ = 4.75, $SD$ = 0.30). To examine within-subject differences as described in section 4.1, data from 14 participants can be used for a "pre"-"post" comparison. For this sub-sample, a paired t-test indicates that the scale values do not differ significantly between the measurement time points "pre" ($M$ = 4.62, $SD$ = 0.36) and "post" ($M$ = 4.72, $SD$ = 0.08) ($t(13) = 0.99$, $p^* > 0.05$). Similarly, "pre"-event attitudes are not significantly different at the "mid"-event point ($t(10) = 0.65$, $p^* > 0.05$).

## 6.3 Evaluation

Six students participated in the final interviews (four male, two female). A qualitative content analysis of the transcripts showed that all six students were *satisfied* with the project overall. The question about the overall impression was positive in each case and praise and approval were expressed. There were also a few negative points regarding the course expressed by each person, which is why the higher category *very satisfied* was not applicable here (section 4.2). This *satisfied* impression was also reflected in the number of sub-categories on the tutorial's perceived strengths and weaknesses. The strengths mentioned could be broken down into 16 sub-categories, twelve of which were addressed by at least three of the six interviewed. In contrast, the weaknesses were made up of four sub-categories, two of which were addressed by at least half of the subjects. The main categories mentioned by at least three out of six students are listed in Table 3. Student names used in the following are pseudonyms.

All students highlighted the tutorial's focus on digital tools and its relation to their own learning processes by statements such as "I think it promoted for me, in terms of the simulations, what you would now call *discovery learning with students*" (Markus). The most frequent category to which all persons responded (a total of 15 times) was *learning as a future teacher*. It included statements on the expansion of one's own experience and competencies with regard to the teaching profession. Quotes such as "in any case, concerning my competencies as a teacher, it has definitely brought me forward" (Emma) refer to aspects of the tutorial that were considered significant or useful for the future profession of teaching. This can also be seen in statements concerning the fact that students' expectations of the teacher training program with regard to course design, competence promotion or knowledge transfer were met in this tutorial: "And somehow this is also something that the teacher training program should actually do" (Markus; in this regard, four other students commented similarly). As one part of the course design, five students reported the didactic basis beneficial and Jan even elaborates on its link to astronomy in this regard, saying "I believe that the didactic part, especially in connection with a certain topic, in this case astronomy, opens doors." The opportunity to gain practical experience in teaching astronomy with digital tools (six respondents) as well as the related support in planning (3) were also highlighted. Learning and working in small groups during sessions (five respondents) as well as during teaching (3) was perceived positively. Furthermore, the team teaching approach ("but right then having two experts, I thought that was also pretty cool", Jan) and the tutors work in general were also appreciated by four persons. The overall workload was reported to be reasonable by three students. Preparation for a final written assignment was presented as a strength by five persons and three students emphasized such an examination format as profitable and particularly appropriate.

**Table 3.** Main perceived strengths (top) and weaknesses (bottom) of the astronomy tutorial.

| Main subcategories | Students | Frequency |
|---|---|---|
| Learning as a future teacher | 6 | 15 |
| Digital tools | 6 | 11 |
| Practical experience with pupils | 6 | 6 |
| Didactic basis | 5 | 10 |
| Preparation for written assignment | 5 | 5 |
| Group work during sessions | 5 | 5 |
| Fulfilled expectations | 4 | 11 |
| Tutors work | 4 | 7 |
| Group work during teaching | 3 | 5 |
| Assistance with lesson planning | 3 | 4 |
| Adequate workload | 3 | 3 |
| Examination format: written assignment | 3 | 3 |
| Preparation for exam | 4 | 7 |
| Interplay with lecture | 4 | 6 |

"So it was a bit of a pity that at some point the lecture lagged a bit behind the exercise" (Emma) is a statement on the tutorials interplay with the lecture as one common module. The partial lack of temporal subject synchronization between the lecture and the tutorial was also seen as a weakness by three other students. This category thereby also includes statements such as "in retrospect, I would say that I missed sessions for an [in-depth understanding of] lecture content a little bit" (Markus). The ability of the students to prepare for the final exam, which was originally intended to be in the form of a classic written examination, was criticized by four students: "concerning an exam, the tutorial has confused me a lot, because I did not know how it would fit in" (Lena).

Overall, the students' feedback on the usefulness of the digital tools, the didactic background, as well as the fit to the astronomy lecture content was positive. They evaluated the digital tools ($M$ = 5.00, $SD$ = 0.82) and the didactic basis ($M$ = 5.06, $SD$ = 0.85) as useful for their learning process. In addition, both, the digital tools ($M$ = 4.88, $SD$ = 0.72) and the didactic basis ($M$ = 4.88, $SD$ = 0.81), were perceived as aligned with the astronomical content.

## 6.4 Manipulation Check

A comparison of the astronomy tutorial with traditional tutorials for preservice teachers in the bachelor's program shows that didactic knowledge ($t(10.55) = 3.63$, $p^* < 0.05$, $d = 1.76$) and digital competencies ($t(10.55) = 5.83$, $p^* < 0.01$, $d = 2.35$) are significantly more often addressed in the astronomy tutorial with large effect. Between the two independent samples no significant difference in terms of content knowledge was found after a Bonferroni correction ($t(21.17) = –2.62$, $p^* > 0.05$). Students similarly valued content knowledge ($M$ = 4.44, $SD$ = 1.31), didactic knowledge ($M$ = 4.63, $SD$ = 0.72) and digital competencies ($M$ = 4.31, $SD$ = 0.75). In traditional physics tutorials, content knowledge ($M$ = 5.40, $SD$ = 0.52) seems to be more meaningful, whereas didactic knowledge ($M$ = 2.30, $SD$ = 1.95) and digital competencies ($M$ = 2.14, $SD$ = 1.16) seem to be less relevant according to the students surveyed.

In Figure 6, the digital competencies scale used is broken down into its individual competence areas (Becker et al., 2020). Digital simulation and modeling as science-specific areas ($M$ = 5.19, $SD$ = 0.54), and digital communication and collaboration ($M$ = 4.81, $SD$ = 1.11), documentation ($M$ = 4.63, $SD$ = 1.20) and research and evaluation ($M$ = 4.50, $SD$ = 0.97) as more general areas were all rated as meaningful. In contrast, all areas of competence tended not to be assessed as required in the tradi-

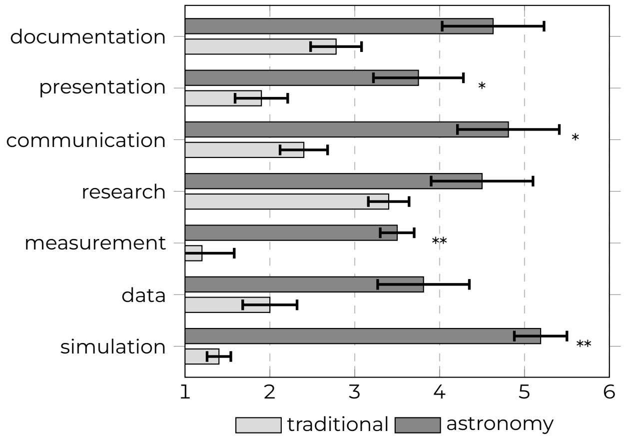


**Figure 6.** Itemization of the competence areas to the used scale of digital competencies in the Manipulation Check. Descriptive results on astronomy tutorial are contrasted with those from traditional tutorials. Error bars indicate the standard errors of the mean values.

tional tutorials: here, digital research and evaluation is ranked highest with a mean of 3.40 ($SD = 1.90$), digital simulation and modeling ($M = 1.40$, $SD = 0.97$) and measurement and data acquisition ($M = 1.20$, $SD = 0.63$) are ranked lowest. Thus, compared to traditional physics tutorials, the astronomy tutorial is evaluated as significantly more important for digital competencies in presentation ($t(24.00) = 3.25$, $p^* < 0.05$), communication and collaboration ($t(12.90) = 3.65$, $p^* < 0.05$), measurement and data acquisition ($t(21.77) = 3.10$, $p^* < 0.001$) and, finally, simulation and modeling ($t(24.00) = 12.85$, $p^* < 0.001$).

## 7 Discussion

In this section the results presented are discussed in light of the research questions.

**Q1** *How do the students' TPACK self-assessments of the technology-related components change during the course?* Overall, preservice physics teachers self-assessed their technology-related teaching skills as rather low before participating in the astronomy tutorial, even though they rated their nominal technological knowledge as rather high. One reason for this rather low self-assessment may be the lack of comprehensive, university-wide offerings of obligatory modules for the standardized promotion of media education competence (Schiefner-Rohs, 2012). This is also reflected, for example, in the students reporting very little prior experience using digital tools in teaching, even though they are Master's students who have already completed more than half of their studies and at least one school internship. The tutorial extended the students' experience in this regard, as they were instructed to plan and perform an astronomy lesson including digital tools (simulation, spreadsheet). The fact that their self-assessed technological knowledge stands out could be because they have acquired new digital skills during the pandemic-driven virtual teaching since April 2020. Nevertheless, this is only conjecture and further research would be necessary in this regard.

After participating in the tutorial and compared to their experiences before, students reported an increase in competence in all areas queried. Effect sizes are notably large in each case ($d > 1$). We assume that this can be attributed to the retrospective survey method (Drennan and Hyde, 2008; Lam and Bengo, 2003). Moreover, they generally rated their digital competencies as rather high. Specifically, changes in the TK could only be detected after the second half of the tutorial. This could be due to the fact that the didactic basis was completed and the subject-specific, digitally-based elements had become the priority (section 4.3). Since there is no comparison group, the increase in competence cannot be directly attributed to the intervention. However, students indicated that various digital competencies were addressed in the tutorial, which suggests the acquisition of competencies through the intervention. This is also supported by the fact that, in the interviews, students explicitly commented on the acquisition of such competencies in context of this tutorial.

**Q2** *How does students' attitude towards learning with digital media change after participating in the course?* An expected change in students' attitude towards learning with digital media was not found. Due to the scale's low internal consistency, it cannot be contrarily concluded that the intervention did not influence the students' attitude. Krause et al. (2017) distinguished between general and discipline specific attitudes in a study with chemistry preservice teachers; this could be an approach to explore attitudes more deeply in order to better understand them. Nevertheless, analysis shows that the students are positive about learning with digital media (section 6.2). Interview statements such as "My plan is to become quite a digital teacher later on" (Markus) and "I am positive about digital media use" (Emma) support this finding. Three students also report concrete ideas for future use of digital tools, for example: "Stellarium was a great tool, which I can imagine using" (Jan) and "[this experiment] can be replaced by a simulation" (Karl). Thus, the students express their intention to use technologies in classroom – according to TPB, central for an actual behavior (section 3.2).

**Q3** *How do the students evaluate the course?* The new tutorial teaching concept was perceived as satisfactory and useful overall. Participants appreciated the opportunity to gain their own experience with digital tools from a learning perspective on one hand and a teaching perspective on the other. Methodological aspects of the tutorial were found to be beneficial. It turned out that this concept was very close to the students' ideas and demands on how a university course should be designed to best prepare them for teaching profession. Moreover, the digital tools used were found to match the astronomical content. Also, the special role of simulation in context of astronomy was perceived by the students.

The tutorial concept will be revised with regard to the weaknesses that have been identified before it is implemented again in the next winter semester. By more timed and coordinated planning with those responsible for the lecture, the interaction between the tutorial and the lecture should be improved so that astronomical content is addressed in the lecture first and in the tutorial afterwards. In section 6.3 a statement by Markus on the desired in-depth study of astronomy content was quoted. Later on, he commented on the teacher training benefits: "You can't have both [reference to teaching profession and astronomical in-depth understanding] anywhere, of course." This example indicates that students perceived some reduction in subject content in the tutorial compared to typical courses, but welcomed this shift in focus ("on the whole, I would actually rate the tutorial as better now", Markus).

All in all, the approach presented here enables an innovative and authentic engagement with currently relevant scientific topics and methods. The approach integrates modern, digitally-based methods for gaining knowledge and a teacher training component into an existing astronomy-specific module. In combination with didactic elements, such a course concept leads to the expansion of classroom-relevant digital competencies among preservice teachers. In this study, students not only possess the relevant digital competencies but also have a positive attitude. Building on the assumed relationship between TPB and TPACK (digital competencies and attitude affect intention to use technology), it can be expected that they intend to use technology and will actually implement it in their classroom in future. Thus, this course concept could be an approach for breaking a vicious circle: students who start their studies at university with few digital skills and receive insufficient support in this regard at university are likely to end up giving their pupils a poor media education (Kammerl and Ostermann, 2010). Based on our results, there is considerable room for improvement. A limitation results from the fact that the students' astronomical knowledge was not measured. On average, however, the final exams indicated a good level of astronomy knowledge on the part of the students. Furthermore, a follow-up study could assess the sustainability of digital competencies learned as well as the extent of actual long-term technology incorporation into teaching.

# 8 Potential implications

Astronomy is a science with particular scientific, historical, and cultural facets that make it a wonderful means of integrating different fields within secondary education. However, the particular aspects of modern astrophysics—the need for remote-sensing, the dominance of image-based data collection, and the strong role played by numerical simulations—create a situation where a digitally-based system of instruction that captures the essence of a modern scientific field of inquiry can be implemented in the school classroom using relatively simple means. This type of instruction can easily be integrated into university courses to help prepare future teachers by improving their relevant digital competencies (Fig. 4). Our participants now have access to a pool of different tools that they have already dealt with in detail, tools they can modify easily without needing deep programming skills, and they can even create their own meaningful simulations with software that is standard in classrooms (e.g. `GeoGebra`, `Snap!`, spreadsheets). In principle, the concept can also be transferred to other physical or scientific fields.

The goal of promoting digital competence among preservice teachers can just as easily be extended to promoting the digital competencies of their future pupils. Leaving the didactic elements aside and focusing on learning astronomy with digital tools, the digital learning environments developed here, particularly the creation of simulations (Table 2), can be used effectively in school classrooms.

# 9 Availability of supporting data and materials

The materials developed for this tutorial and this research are available upon request from the authors.

# 10 Declarations

## 10.1 List of abbreviations

- *CK:* Content Knowledge
- *M.Ed.:* Master of Education
- *mid:* Midtest
- *M.Sc.:* Master of Science
- *PCK:* Pedagogical Content Knowledge
- *PK:* Pedagogical Knowledge
- *post:* Posttest
- *pre:* Pretest
- *TCK:* Technological Content Knowledge
- *TK:* Technological Knowledge
- *TPACK:* Technological Pedagogical and Content Knowledge
- *TPK:* Technological Pedagogical Knowledge

## 10.2 Ethical Approval

The need for approval was waived.

## 10.3 Consent for publication

Persons consented to saving, further processing and publication of data for research purposes in anonymous form before the interviews were conducted and before answering the questionnaires. We have followed national guidelines on data collection according to General Data Protection Regulation (GDPR, Regulation (EU) 2016/679).

## 10.4 Competing Interests

The authors declare that they have no competing interests.

## 10.5 Funding

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## 10.6 Author's Contributions

Ronja Langendorf designed the course concept and performed the tutorial as one of two tutors. She carried out the research and analysed the data. Ronja Langendorf and Frederic V. Hessman designed the digital tools and instructions. Both contributed to the manuscript. Susanne Schneider supervised the project and provided critical feedback on intervention, research and the manuscript.

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