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# Factors influencing the development of pre-service science teachers' technological pedagogical content knowledge in a pedagogical makerspace

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In an increasingly digitalized world, pre-service and in-service teachers need subject-specific didactic competencies to be able to plan their lessons appropriately and use their knowledge to promote digital competencies among students. Building on competency models such as the Technological pedagogical content knowledge (TPACK) framework, this article explores the extent to which specific digital competencies relevant to pre-service teachers can be developed through project work in a pedagogical makerspace and examines the extent to which contextual factors such as technological self-efficacy, motivation and technology acceptance influence the development of pre-service teachers' TPACK and their intention to use digital media. To this end, 495 pre-service science teachers from both intervention and control groups completed a pre-post digital questionnaire before and after the intervention. The data were used for structural equation modeling. The results show that the level of TPACK before the intervention is an important predictor of TPACK after project work. Furthermore, TPACK before the intervention positively influences pre-service teachers' intention to use digital media in the future. Also, the perceived usefulness for professional use and the intention to use information and communication technologies (ICT) are strongly influenced by TPACK. Consequently, it appears significant to enable a low-threshold entry point at the beginning of the study to provide a solid foundation upon which more advanced TPACK can be built. Motivation and technology acceptance are strongly correlated. Therefore, teacher training should focus on motivation and acceptance of technology.

KEYWORDS

**pedagogical makerspace, teacher professional development, TPACK, technology acceptance, digital media**

## 1 Introduction

Digital media influence people's social, professional, and political lives and have the potential to fundamentally change the learning culture in schools (Becker et al., 2020; Eickelmann and Gerick, 2020). Due to their digitality, digital technologies represent a new cultural technique that can be seen, for example, in new fields of scientific research. This includes, for example, data mining, *in silico* research or working on and dealing with large language models. Therefore, teacher education needs to adopt and teach the newly added competencies based on theoretically grounded competency models. The Technological pedagogical content knowledge (TPACK) model is widely used as a framework to describe competencies teachers need to acquire (Mishra and Koehler, 2006, 2008). Yet it does not fully cover the extensions included under the concept of "digitality." Newer models, such as the DPACK model are more differentiated regarding the integration of digitality-related aspects (Huwer et al., 2019; Thyssen et al., 2023). In this study, however, the TPACK model was chosen because the DPACK model was not yet available in its current form at the time the research was started, and the competencies addressed in the project work in the makerspace were also well covered by the TPACK model. The aim of the present study was to investigate the development of TPACK of pre-service teachers working with digital media in a pedagogical makerspace project. In particular, it aimed to identify factors that influence the development of TPACK.

## 1.1 The pedagogical makerspace as learning environment

In recent years, makerspaces have been increasingly recognized as suitable and authentic learning environments for promoting TPACK, for example through design projects (Tondeur et al., 2012; Baran and Uygun, 2016; Wang et al., 2018; Max et al., 2023). Makerspaces usually provide space and a wide range of analogue and digital equipment for users, i.e., makers who create and tinkerers who improve existing products, to create, revise or optimize any kind of analogue or digital product (Fraunhofer IAO, 2018; Knaus and Schmidt, 2020; Max et al., 2021). A pedagogical makerspace is associated with an educational institution. Projects carried out in these spaces are led by teachers and the aim is to increase competences through the creation of a product, such as STEAM-related knowledge and skills or 21st century skills such as communication, collaboration, creativity, problem solving or digital competences (e.g., Konstantinou et al., 2021; González-Pérez and Ramírez-Montoya, 2022). Working in a makerspace is characterized by a number of features:

(1) Makers work on concrete problems on their own initiative.
(2) Making is regarded as an iterative process, changing flexibly among construction, testing, and revision to result in solutions that can be shared after completion (Bevan, 2017; Heredia and Tan, 2021).
(3) Engagement in a makerspace is independent of a maker's prior experience and competencies, thereby contributing to educational equity (Ismer and Mietzner, 2019; Knaus and Schmidt, 2020; Heredia and Tan, 2021; Mersand, 2021). This aspect is also relevant in the context of digitalization and digital poverty.
(4) Making is highly individualized (Ismer and Mietzner, 2019; Knaus and Schmidt, 2020). It not only enables temporal flexibility (Heredia and Tan, 2021), but also allows makers to select their own working methods in line with their own learning styles, thus resulting in kinesthetic experiences in addition to the use of (digital) auditory and visual media (Blackley et al., 2017).
(5) A makerspace is a space with an "open mistake" culture, where productive failure is not only tolerated but even desired (Cross, 2017; Schön, 2018; Heredia and Tan, 2021). Reservations and uncertainties about any kind of technology are reduced through active participation (Hilton et al., 2018). This refers of course also to digital technologies. Makerspace are therefore places in which digitalization and the development of digital literacy take on a significant role.

In a pedagogical makerspace, pre-service teachers can learn how to work in a makerspace and implement making as a highly constructivist learning process (Kurti et al., 2014; Cross, 2017). This can be realized by pre-service teachers carrying out their own projects in the makerspace or accompanying students in their projects, similar to a teaching-learning laboratory. Through this approach, pedagogical makerspaces promise to help teachers develop innovative media practices, which are important in the pedagogical context to acquire TPACK in action (Olofson et al., 2016; Petko et al., 2018). Given that TPACK is to be developed in a self-directed and self-exploratory way in a diverse learning environment, creative projects in a makerspace seem to be appropriate learning opportunities to support the development of TPACK. The aim of this study was to determine whether TPACK could be enhanced by conducting a project in a pedagogical makerspace. In addition, this study also investigated the factors that influence the development of TPACK while working and learning in a pedagogical makerspace. By knowing these factors, training can be designed in a more appropriate and constructive way.

## 1.2 Technological pedagogical content knowledge framework

The TPACK model of Mishra and Koehler (2006, 2008) established an essential and necessary interconnection between Shulman (1986), describing the constitutive pedagogical content knowledge (PCK) of teachers, and the growing technological knowledge of modern information and communication media required by the prevailing digital transformation (Angeli et al., 2016). In this context, technological knowledge (TK) is incorporated in pedagogical content knowledge (PCK). In recent research, digital media as a component of TK has received the most attention. With TK as the interface of content knowledge (CK) and pedagogical knowledge (PK), the TPACK model is the conglomeration of these three facets. TPACK describes the knowledge and skills required to select technology professionally and reflectively (e.g., digital media) for domain-specific teaching and use it in teaching processes (Schmidt et al., 2009). Among the basic knowledge domains, in addition to PCK, there is also technological content knowledge (TCK), which describes technologies, that are of central importance above all for the subject context, and their application, as well as technological pedagogical knowledge (TPK), which is dedicated to the use of digital media in teaching-learning settings in a manner that promotes learning. Both are subsets of the more complex TPACK, which is intended to enable pre-service teachers to implement subject lessons meaningfully with the effective support of digital media and technologies as soon as they start teaching (Mourlam et al., 2021).

## 1.3 Factors influencing the development of technological pedagogical content knowledge

When pre-service teachers conduct projects in a makerspace in which they create digital learning products, TPACK can be perceived as a prerequisite as well as a desired result (Cross, 2017). In a typical makerspace, project groups work together to create a product. By doing so, different technologies, media and materials are used, which increases their TK. Also, project groups are influencing and supporting each other, share experiences, cope with failure and start anew with a different approach. By doing so, important competences for PK are fostered like communication, collaboration and experience sharing. Moreover, in designing learning products, they have to use their PK to be able to create useful and meaningful learning products. When designing subject-specific learning products, also their CK is fostered and used.

The extent to which pre-service teachers use technologies in their work depends on the resources available, such as training material (Tondeur et al., 2012) and the support provided by learning facilitators or experts (Fernandes et al., 2020). The scope also depends on personal factors such as technological self-efficacy (TSE), technology acceptance (TAM) and intrinsic motivation to use digital media (IMDM). Both factors affect pre-service teachers' learning experience and may influence the development of TPACK as well as their intention to use digital media (IUDM). The used concepts and their abbreviation can be found in Table 1.

### 1.3.1 Technological self-efficacy

Technological self-efficacy is a person's belief in their ability to perform a particular task or achieve a goal through the use of technology (Holden and Rada, 2011). In contrast to TPACK, which is professional-related, it is not related to using technology for teaching, but for daily life. It is hence a more general construct of technological self-efficacy. It allows people to successfully master tasks despite any difficulties they are facing (Bandura, 1986; Yamamoto, 2021). This means that TSE can influence a (pre-service) teacher's confidence in the purposeful and successful use of digital media for personal (subject-related) application, the design of teaching-learning materials, or the use of digital media in the teaching context, and thus the application of TPACK. Experiences with digital media positively increases TSE as well as TPACK (Abbitt, 2011; Joo et al., 2018; Lachner et al., 2021; Zahwa et al., 2021). Furthermore, studies report a positive relationship between TSE in working with digital media and a person's intrinsic motivation to complete tasks using digital media (IMDM; Niederhauser and Lindstrom, 2018; Vogelsang et al., 2019; Lachner et al., 2021; Yamamoto, 2021). According to Yamamoto (2021), IMDM is a central component of TSE, whereas Lachner et al. (2021) classified TSE together with the intention to use digital media (IUDM) for teaching-learning processes as components of IMDM. While statistical studies have been able to identify TSE as a predictor of technology acceptance (Holden and Rada, 2011), this has so far been in connection with in-service teachers, but not with pre-service teachers.

TABLE 1 Abbreviations of the used concepts.

| IMDM | Intrinsic motivation to use digital media |
|---|---|
| IUDM | Intention to use digital media |
| TPACK | Technological Pedagogical Content Knowledge |
| TAM | Technology Acceptance (Model) |
| TSE | Technological self-efficacy |

### 1.3.2 Technology acceptance

Technology acceptance describes how users accept the use of digital media (Holden and Rada, 2011). The Technology Acceptance Model (TAM; Davis, 1989) describes the perceived ease of use and perceived usefulness as core factors, which in this context influence a (pre-service) teacher's decisions as to when and how to use digital media for planning, designing, and implementing lessons. Perceived ease of use is important in education because it describes how effectively, efficiently, confidently, and easily a digital medium can be used, thereby meeting the demands for flexibility and adaptability to learners' individual needs (Holden and Rada, 2011). Perceived usefulness describes a (preservice) teacher's expectations of the usefulness of a digital medium for their teaching (Vogelsang et al., 2019). The more useful and essential a digital medium is perceived to be for the teaching process, the higher are the attitudes toward its use (Teo, 2012; Scherer et al., 2018) and the teachers' IUDM to design effective teaching-learning settings (Holden and Rada, 2011; Mei et al., 2017). The evaluation of a digital medium and its usefulness for the subject context are among the "TPACK-in-action" practices that can be predetermined by TPACK as a predictor (Joo et al., 2018). That means, that only if acceptance toward digital media is sufficiently high enough to use them, the (preservice) teachers are ready to improve their TPACK. Conversely, the existing knowledge influences TAM's perceived ease of use and perceived usefulness (Mayer and Girwidz, 2019; Thohir et al., 2023). Similarly, TSE is thought to have a significant impact on TAM (Holden and Rada, 2011; Yamamoto, 2021).

### 1.3.3 Intrinsic motivation to use digital media

Motivation is expressed in terms of the purposefulness, persistence, and intensity of human behavior (Ryan and Deci, 2000; Wilde et al., 2009). In terms of engagement with digital media, a pre-service teacher's high intrinsic motivation to use digital media (IMDM) is reflected in a strong commitment and desire to learn how to integrate and use digital media in a manner that promotes learning (Yamamoto, 2021). The increasing motivation to take up the challenge of designing technology-enhanced subject teaching in a meaningful way means simultaneously exploring the links among technological, pedagogical, and content knowledge (Sojanah et al., 2021). In contrast to pre-service teachers (i.e., those without teaching experience), the focus of in-service teachers is often more on the added value that the digital medium brings to the planning, design, and implementation of lessons (Backfisch et al., 2020). Predictors of IMDM are attitudes toward digital media (Vogelsang et al., 2019). Likewise, TSE is also thought to be a predictor (Lachner et al., 2021). Furthermore, due to the multi-layered nature of the construct, Lachner et al. (2021) described the need to further empirically investigate possible interactions with other constructs such as TAM or perceived usefulness (as a component of technology acceptance, see also Davis, 1989) in the field of teacher education.

### 1.3.4 Intention to use digital media

Intentions as behavioral purposes are factors that indicate how much a person is willing to behave in a certain way (Teo, 2012), i.e., with what willingness a (pre-service) teacher will engage with digital media. Accordingly, a higher readiness to use digital media can also result in an increased engagement with digital media for the subject-specific teaching context, which will foster TPACK. On the other hand, a sufficient level of TPACK will also increase the intention to use digital media in teaching. Although the effects of TPACK on IUDM were measured as being significant by Liu (2011), this result has not been confirmed by other studies (Joo et al., 2018; Lachner et al., 2021). Lachner et al. (2021) assumed so-called ceiling effects for the measurements in their TPACK intervention study, suggesting that the readiness of pre-service teachers to engage with digital media was already so high at the beginning that no significant increase over time was possible. The quality of the perceived teacher training was also found influencing the intention to use digital media (Paetsch and Drechsel, 2021). With respect to makerspace learning, it is assumed that the increase in TPACK will also increase IUDM. In addition, numerous studies have reported significant influences of attitudes toward digital media (Liu, 2011; Teo, 2012; Guggemos and Seufert, 2021) and TAM (Holden and Rada, 2011; Teo, 2012; Yamamoto, 2021) on IUDM. Self-efficacy was also studied as a predictor but had no significant impact in this context (Teo and Zhou, 2014; Mei et al., 2017).

## 1.4 Research questions

The need to create specific learning environments that will enable pre-service teachers to develop TPACK in practice, regardless of their previous experience, has drawn the attention of university teacher education to the makerspace as an open constructivist teaching-learning environment (Kurti et al., 2014; Cross, 2017; Mersand, 2021). A makerspace has characteristics that support active, subject-based teaching-learning experiences through collaborative design activities of teaching material (Knaus and Schmidt, 2020; Max et al., 2021). The creative occupation with teaching and learning by means of modern (digital) tools is supposed to foster TPACK. Whether these technological learning experiences indeed lead pre-service teachers to rate their TPACK higher may depend on additional influencing factors (see "Factors influencing the development of TPACK"). When and how they use digital media to plan, design, and deliver lessons may be related to their TAM and IMDM. These factors appear to be closely linked to TSE. Depending on the willingness with which a (pre-service) teacher engages with digital media, this may also lead to an increased IUDM for the subject-specific teaching context and thus to the application of TPACK, which is a prerequisite for its development. In order to examine the development of TPACK in relation to the influencing factors, the following research question was developed:

How does TPACK, influenced by the predictors technological self-efficacy (TSEt1), intrinsic motivation (IMDMt1), and technology acceptance (TAMt1), develop in pre-service teachers through their work in the pedagogical makerspace (TPACKt1 to TPACKt2) and how does this influence their intention to use digital media (IUDMt2)? Different recommendations for developing TPACK-promoting elements in teacher education justify this question.

# 2 Methodology

## 2.1 Design of intervention

Since the makerspace as a space for individual learning processes in a pedagogical context appears to promise to meet the demand for innovative media practices (Petko et al., 2018) and to enable experiencing one's own agency as a component of teacher professionalization (Lipowsky and Rzejak, 2017), media projects developing teaching-learning material conducted in a pedagogical makerspace served as the intervention to promote TPACK in an authentic context (Tondeur et al., 2012; Wang et al., 2018). They were integrated into the existing curricular teaching. Access to the makerspace was organized individually and flexibly by learners at any time during their studies (in this context, strict coordination was necessary during the COVID pandemic).

The pre-service teachers who participated in the study took a compulsory seminar (spread over 14 weeks) as part of their studies in their respective scientific and mathematical subjects (biology, chemistry, physics, psychology, and mathematics), which included the integration of a subject-related media project across the semester. The seminar was divided into two main parts (see Figure 1). In the first part, the pre-service teachers worked on an online-based theoretical input (for approximately 180 min), which addressed TPACK in five lessons, sometimes with the help of examples (e.g., dealing with biological animations in biology lessons) and provided hints on how digital technologies could be integrated into subject lessons. The theoretical input introduced criteria for good science teaching (Steffensky and Neuhaus, 2018), aspects of media pedagogical theories (cognitive load theory; Chandler and Sweller, 1992) cognitive theory of multimedia learning (Mayer, 2009), the Substitution, Augmentation, Modification, and Redefinition (SAMR) model (Puetendura, 2006, 2010), and basic rules on self-organization in project groups. Subsequently, the pre-service teachers carried out a media project in an iterative design and production process (Max et al., 2021, 2023).

Each pre-service teacher had the opportunity to use the digital and analogue media offered by the university's pedagogical makerspace to develop their ideas and produce teaching/learning material on a problem of a subject-specific topic (e.g., the creation of a subject-specific explanatory video; Lukas et al., 2019; Max et al., 2020). The pedagogical makerspace offered analogue and digital equipment and software (i.e., cameras, green screens, audio recording systems, iPads, lighting, recording stations, computers with editing software for audio stories, podcasts and videos, a 3D scanner and printer, and cutting plotters). Work with this diverse hardware and software was supported by digital instruction manuals with numerous tutorials, consulting offers, and workshops.

The pre-service teachers worked in groups that were freely formed at the beginning of the semester. The project specifications combined classical and agile elements of project management with a focus on an iterative design process that combines several cycles in which the steps of doing, analyzing, and reflecting constantly alternate (Max et al., 2021). In the beginning, the project groups were supervised more intensively. More scaffolding was provided at that time (e.g., in the definition of project goals) and quickly decreased during the course of the project. Nevertheless, the project work was accompanied by

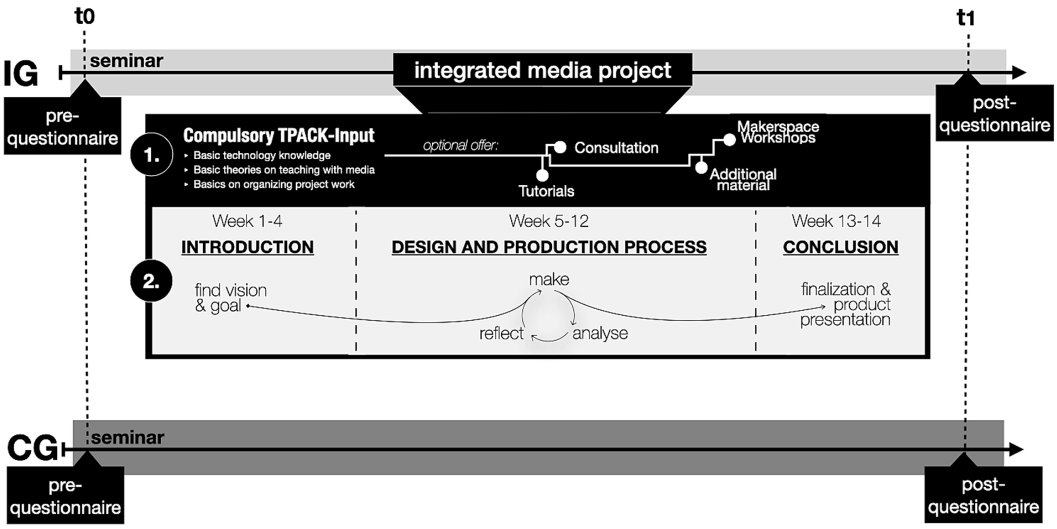


FIGURE 1
Overview of the cross-semester media project with three main project phases, evaluation points, student activities, and Technological pedagogical content knowledge (TPACK)-related compulsory input for the intervention group (IG) in comparison with the control group (CG).

regular rounds of reflection integrated in the seminar (see Figure 1). The instructors recorded the needs as well as perceived challenges and provided individual and project-specific problem-solving strategies in addition to the input, so that TK could be meaningfully linked with CK and PK (Cohen, 2017).

## 2.2 Sample

The sample comprised N = 495 pre-service science teachers (male = 108; female = 387) in four cohorts (C; C1 = 29; C2 = 169; C3 = 148; C4 = 149). Of these, N = 268 in the intervention group (IG) underwent the intervention by attending the compulsory seminar as part of their bachelor's or master's degree programs, while carrying out their media project in the makerspace. The compulsory seminar was newly included into teacher education through this project. Since the design of digital media had not been a standard part of the teacher education program in the past and no courses were offered in this area prior to the project, a similar level of knowledge in ICT design could be assumed in the bachelor's and master's programs. The control group (CG) with N = 227 neither gained experience in makerspace work nor received the TPACK-related input. All participants were either in their late bachelor's or early master's studies and were hence comparable considering their study progress.

## 2.3 Measures

We measured TPACK, TSE, TAM, and IMDM before the intervention ($t_1$) and TPACK as direct dependent variable after the intervention. As we were interested to see if also the intention to use digital media could be associated with (assumed) enhanced TPACK, also IUDM was measured after the intervention ($t_2$). All measures were raised with self-assessment scales.

### 2.3.1 Technological pedagogical content knowledge

The TPACK scale consists of 13 items from the standardized TPACK questionnaires by Schmidt et al. (2009) (four items) and Handal et al. (2013) (nine items). By combining the scales, the pre-service teachers assessed their TPACK more generally, e.g., "I can teach lessons that appropriately combine literacy, technologies, and instructional approaches" (Schmidt et al., 2009, p. 135), as well as in a slightly more subject-specific manner, e.g., "I am able to use technology to explore or present biological [subject] content in different ways" (Handal et al., 2013, p. 31). All TPACK items were scored on a 4-point Likert scale. As TPACK was measured with a self-assessment instrument, it reflects here the role of the student's believe how well they can use modern technology to teach subject-specific content appropriately. It does hence not reflect objective competence. That this can diverge importantly was shown by us in Max et al. (2022). We will refer to this point in the discussion as well.

### 2.3.2 Technological self-efficacy

Technological self-efficacy measures personal confidence in the successful and purposeful use of technology. To answer the items, pre-service teachers had to assess, among other things, the need for support in order to be able to solve (creative) tasks with digital media, e.g., "In general, I can do any task I want with a digital medium as long as I can ask someone for help when I get stuck" (Holden and Rada, 2011). Although the scale was originally based on 10 items, it was shortened on the basis of an explorative factor analysis and thus validated in terms of content. The shortened version with six items was translated into German and was scored on a 4-point Likert scale.

### 2.3.3 Technology acceptance

The TAM scale adapted from Holden and Rada (2011) measures the perceived ease of use as well as the usability and flexibility to use certain technologies. It was translated into German for this research. The scale comprises nine items, e.g., "My interaction with the technology is clear and understandable," "Interacting with the technology does not require a lot of my mental effort," etc., all scored on a 4-point Likert scale.

### 2.3.4 Intrinsic motivation to use digital media

To measure the intrinsic motivation of pre-service teachers in relation to working with digital media, the short scale of intrinsic motivation (KIM) by Wilde et al. (2009) was used, e.g., "I find it very interesting to work with digital media." This consists of four subscales: interest/enjoyment, perceived competence, perceived choice, and pressure/tension. All items were scored on a 5-point Likert scale in accordance with the original measure. For better comparability between the constructs, the scale was afterward converted to a 4-point Likert scale. The conversion was done as follows: the value 1 remained 1, the value 5 was set to 4. Three was then divided by 4 to obtain a proportional gradation in five steps between 1 and 4 (i.e., 1, 1.75, 2.5, 3.25, 4).

### 2.3.5 Intention to use digital media

The IUDM for subject lessons was measured with five items adapted and translated from Ehmke et al. (2004). Items such as "I will look for meaningful ways to use digital media in my teaching in the future" were scored on a 4-point Likert scale.

For each of the above described scale and the respective timepoint, a reliability analysis was conducted. The analysis provided "good" to "very good" results (Dorsch and Wirtz, 2020; Table 2).

## 2.4 Research design

A digital pre-post questionnaire was completed by the pre-service teachers at the beginning (t1) and end of the semester (t2; see Figure 2). The sample comprises N = 257 incomplete data sets, as a large proportion of students participated in the pre-survey but not the post-survey (there was a high drop-out rate, e.g., due to opting out of seminars or studies and the excessive demands during online classes due to the COVID-19 pandemic). These cases were still included in the analysis because structural equation modeling is capable of handling them with maximum likelihood estimation (Geiser, 2011). In addition to working on media projects in the pedagogical makerspace (intervention), the factors TSE, TAM, and IMDM were identified in the literature as central factors influencing the development of TPACK in pre-service teachers. The development could subsequently be expressed, among other things, in the change of IUDM for one's own teaching. A research design was derived from the interplay of effects, which is shown in Figure 2.

Based on the literature, the following hypotheses were formed:

> *H*1: TSEt1 has an impact on TAMt1.
>
> *H*2: TSEt1 has an impact on IMDMt1.
>
> *H*3: IMDMt1 has an impact on TAMt1.
>
> *H*4: IMDMt1 has an impact on TPACKt1.
>
> *H*5: TAMt1 has an impact on TPACKt1.
>
> *H*6: TPACKt1 has an impact on TPACKt2.
>
> *H*7: TPACKt2 has an impact on IUDMt2.

Data on the increase in self-assessment of TPACK as well as other related constructs have already been analyzed and reported for the first three cohorts by the authors (Lukas et al., 2020; Max et al., 2022, 2023). However, the interaction of TPACK with other factors before and after the project work in the makerspace had not been reported until now.

**TABLE 2** Reliabilities ($t_1$ = pre and $t_2$ = post intervention) of the scales used.

| Construct | Cronbach's alpha |
|---|---|
| Technological, pedagogical and content knowledge ($TPACK_{t1}$) | $\alpha = 0.85$ |
| Self-efficacy regarding the use of digital media ($TSE_{t1}$) | $\alpha = 0.73$ |
| Technology Acceptance ($TAM_{t1}$) | $\alpha = 0.9$ |
| Intrinsic Motivation to use digital media ($IMDM_{t1}$) | $\alpha = 0.92$ |
| Technological, pedagogical and content knowledge ($TPACK_{t2}$) | $\alpha = 0.89$ |
| Intention to use digital media ($IUDM_{t2}$) | $\alpha = 0.83$ |

## 2.5 Data analysis

### 2.5.1 Correlation among constructs

In a first step, correlation among the pre-intervention constructs TSEt1, IMDMt1, TAMt1, and TPACK t1 and the post-intervention constructs TPACK t2 and IUDM t2 was investigated with a two-way Pearson correlation analysis with the interval-scaled mean values of the present scales using IBM SPSS.

### 2.5.2 Manifest path analysis for measuring technological pedagogical content knowledge development in relation to constructs

In a second step, manifest path analysis was conducted to examine how TPACK, influenced by the predictors TSEt1, IMDMt1, and TAMt1, developed as a result of working in the pedagogical makerspace and how this affected IUDM (see research design in Figure 2).

Structural equation modeling (SEM) was selected as the evaluation method for this purpose, as it allowed empirical testing of correlation structures and change measurements based on regression analyses between several variables (Geiser, 2011). An autoregressive path was included in the path modeling that connected the longitudinal data available from TPACK at t1 and t2 and could reveal possible changes in TPACK over time (Geiser, 2011). Structural

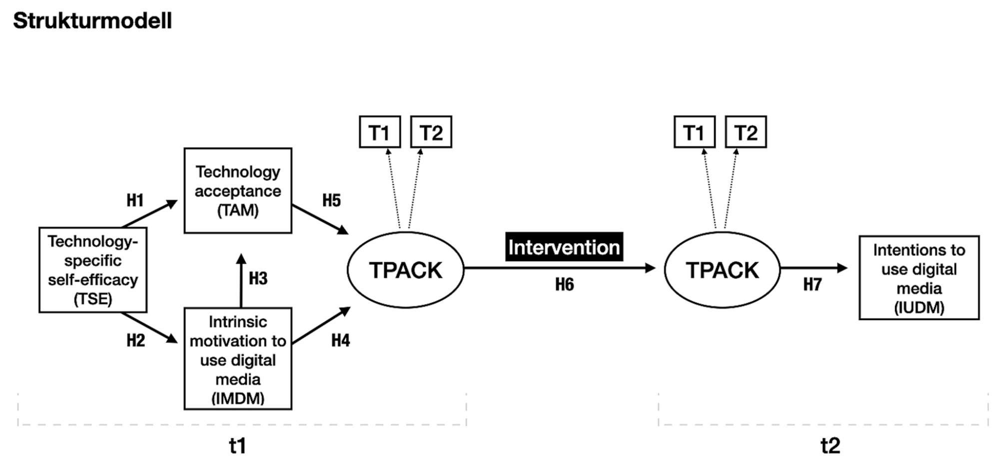


FIGURE 2
Research design with the constructs used over the time before (t1) and after (t2) the intervention.

equation modeling was carried out using Mplus 7.0 as previously employed by Muthén and Muthén (1998–2017). To estimate the theoretical model structure, the maximum likelihood method was applied (Backhaus et al., 2015).

Prior to structural modeling, an exploratory factor analysis (EFA) was calculated in Mplus for each construct. This allowed us to determine whether the items actually loaded on the intended factors to counteract possible unsatisfactory fit indices. Non-fit items were removed until adequate fit indices were achieved. The IMDMt1, TAMt1, TPACKt1, TPACKt2, and IUDMt2 scales each loaded on one factor, confirming validity in addition to content testing. The TSE scale, on the other hand, had to be shortened from 10 to 6 items because the EFA identified two different constructs. After a communicative content validation, the items relevant to the context were selected.

Due to the large number of items (TSEt1 = 10 items, IMDMt1 = 12 items, TAMt1 = 7, TPACKt1 = 9 items, TPACKt2 = 9 items, and IUDMt2 = 5 items), the sample of N = 495 pre-service teachers was found to be relatively small to obtain robust parameter estimates and standard errors. In order to reduce the ratio of model parameters to sample and thus achieve better statistical power for the identification of effects, we utilized item parceling. In this process, individual items are either randomly or specifically combined into one or more packages through the formation of mean values, which then become indicator(s) of the latent target construct (Matsunaga, 2008). In our case, we applied the subset-item-parcel approach (where subscales are combined) and the all-item-parcel approach (scales are combined; Matsunaga, 2008). In the case of the TPACK construct, consisting of the subscales T1 and T2, two parcels were created. For the constructs TSE, IMDM, TAM, and IUDM, only one parcel was created in each case. With the scale mean values, manifest path models were calculated within the framework of structural equation modeling (Geiser, 2011).

Before calculating the scale mean values for each parcel, the reliability was calculated, which provided "good" to "very good" results (Dorsch and Wirtz, 2020; see Table 2). Subsequently, the mean values were examined with boxplots to enable graphically identifying and sorting out outliers (Buttler, 1996). As part of the prerequisite test, it was ascertained whether multicollinearity existed due to the high correlation of the predictors IMDMt1 and TAMt1 (see Table 2). Multicollinearity should not be present, because otherwise it is not known which of the two variables actually contributes to the variance explanation of the endogenous variable, which in this case was TPACK. Here, the VIF value should not have been greater than 10 (Robinson and Schumacker, 2009). In our case, the VIF value was 3.62, so multicollinearity could be excluded.

The overall model fit of the SEM was indicated by the Comparative Fit Index (CFI), Tucker-Lewis Index (*TLI*), and Root Mean Square Error of Approximation (*RMSEA*; Geiser, 2011). Geiser (2011) recommended the following values as model acceptance criteria: $CFI > 0.95$, $TLI > 0.95$, and $RMSEA$ and $SRMR < 0.05$. The Chi-Square test tests the model fit, that is it tests the difference between the observed data and the predicted values of the model. If the Chi-Square is significant, it means that the model does not fit the observed data. However, the Chi-Square test is particularly sensitive to large samples or complex models and can therefore lead to a significant result even with small differences between the observed and expected values (e.g., Schermelleh-Engel et al., 2003).

# 3 Results

## 3.1 Descriptive statistics and correlations of technological pedagogical content knowledge and influencing factors

The descriptive results and correlations of all variables are shown in Table 3. All means were above the scale's median of 2.5 and ranged from 1 to 4 only for IUDMt2. For the other five scales, the minimum was between 1.56 and 2.13 at t1, indicating a positive response tendency to the items. The standard deviations ranged from 0.36 to 0.54, indicating a relatively low dispersion of scores around the mean.

A high correlation at the significance level of $p = 0.01$ was measured among the factors $\text{IMDM}_{t1}$, $\text{TAM}_{t1}$, and $\text{TPACK}_{t1}$ at $t_1$. All three factors do not correlate with $\text{TSE}_{t1}$. Furthermore, all factors measured at $t_1$ (Pre) correlate significantly with the factors measured

TABLE 3 Multiple regression of the factors and descriptive statistics.

| | $R^2$ | $N$ | Mean | $SD$ | $TPACK_{t1}$ | $TAM_{t1}$ | $IMDM_{t1}$ | $TSE_{t1}$ | $TPACK_{t2}$ | $IUDM_{t2}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| $TPACK_{t1}$ | 0.357 | 490 | 2.67 | 0.44 | 1 | 0.462** | 0.505** | 0.067 | 0.381** | 0.254** |
| $TAM_{t1}$ | 0.705 | 488 | 2.91 | 0.54 | | 1 | 0.838** | 0.073 | 0.257** | 0.370** |
| $IMDM_{t1}$ | 0.014 | 488 | 2.90 | 0.51 | | | 1 | 0.040 | 0.313** | 0.346** |
| $TSE_{t1}$ | 0.004 | 480 | 3.02 | 0.36 | | | | 1 | 0.127* | 0.143* |
| $TPACK_{t2}$ | 0.356 | 257 | 2.94 | 0.45 | | | | | 1 | 0.485** |
| $IUDM_{t2}$ | 0.259 | 255 | 3.28 | 0.52 | | | | | | 1 |

$R^2$ = coefficient of determination; $R^2$ indicates what proportion of the variance in the data of the dependent variable can be explained by the estimated model, N, number; SD, standard deviation and correlations (r) of all measures. TPACK, Technological pedagogical content knowledge; TSE, Technological self-efficacy; TAM, Technology acceptance; IMDM, Intrinsic motivation to use digital media; IUDM, Intention to use digital media; t1, pre intervention; t2, post intervention. Two asterisks (**) indicate correlations significant at $p < 0.001$. For the readability of $R^2$: In line 1, $TPACK_{t1}$ represents the dependent variable. The regression model calculates the proportion of the variance of $TPACK_{t1}$ that is explained by the combination of the independent variables $TAM_{t1}$, $IMDM_{t1}$, $TPACK_{t2}$, and $IUDM_{t2}$ (35.7%).

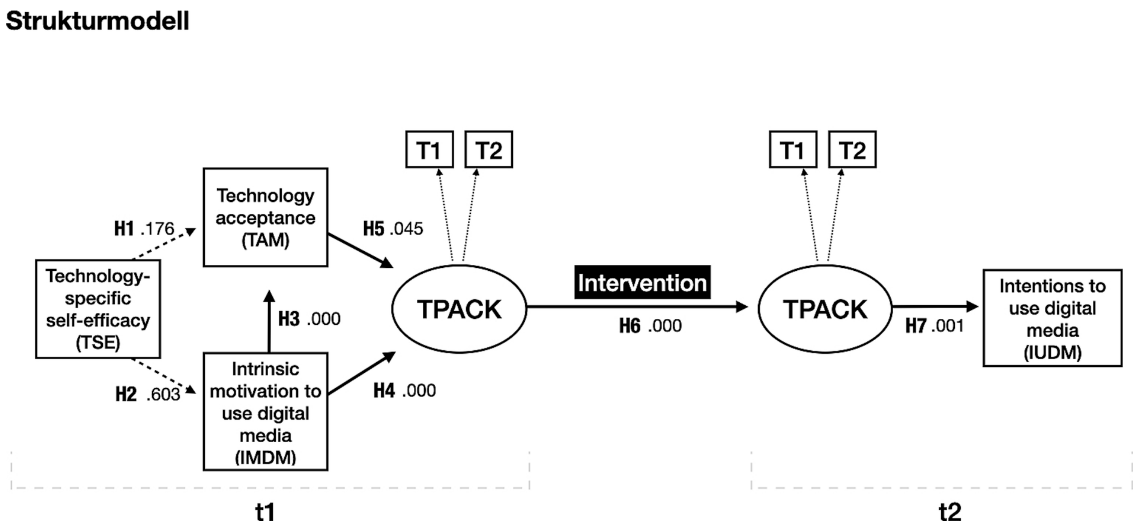


FIGURE 3
Path model of the regression with $p$-values for the hypotheses H1-H7 (solid arrows show significant paths, dashed arrows show not significant paths).

at $t_2$ (Post), $TPACK_{t2}$ and $IUDM_{t2}$, indicating correlation over time (from $t_1$ to $t_2$).

## 3.2 Technological pedagogical content knowledge development and impact influenced by other constructs

We analyzed the extent to which TSE, TAM, IMDM, TPACK, and IUDM interact in a partial longitudinal model. TSEt1 was assumed to be a predictor of IMDMt1 and TAMt1, which are supposed to be predictors of TPACKt1. An autoregressive path was used to test the extent to which the development of TPACK over time (and under the influence of the intervention) depends on itself, i.e., the measured TPACK at t1. In addition, the influence of TPACKt2 on the IUDM of pre-service teachers, e.g., for lesson planning and delivery in the future (IUDMt2), was examined. The fit indices for the manifest path analysis (Figure 3) were satisfactory: $\chi^2 = 55.722$, $df = 25$, $p < 0.001$, $CFI = 0.98$, $TLI = 0.96$, $RMSEA = 0.05$, and $SRMR = 0.042$. Although the Chi-Square test resulted in a significant result, it could be due to the fact that the model is relatively complex. The CFI, TLI, RMSEA and SRMR provided good values.

Table 3 presents the standardized path coefficients for each path analyzed. Furthermore, the quotients of the parameter and quotient error estimates are shown (which can be interpreted as z-values, *cf.* Muthén and Muthén, 1998–2017, p. 798). In addition, the statistical significance of the paths is provided at the levels $** = p < 0.01$ and $* = p < 0.05$. Based on the values given, each hypothesis in this study was either confirmed or rejected (Table 4).

As a result of the analysis, TSEt1 could not be measured as a predictor for TAMt1 and IMDMt1 (H1 and H2 were not supported), even though in earlier studies a relationship among the constructs could be identified for both TAM (Holden and Rada, 2011) and IMDM (Niederhauser and Lindstrom, 2018; Vogelsang et al., 2019; Lachner et al., 2021; Yamamoto, 2021; see also "Technological self-efficacy"). All other hypotheses (H3 to H7) could be supported. The effect sizes according to Cohen (1988) range from small to large effects. The extent to which TPACK develops over time (under the influence of the intervention) depends on TPACK itself (H6), achieving a medium effect.

TABLE 4 Results of the hypothesis tests including the path coefficients, z-values, and p-values (** = $p < 0.01$, * = $p < 0.05$) as well as the statistical power r according to Cohen (1988).

| | Path | Path coefficient | z-value | Statistical power r (Cohen, 1988) | Decision |
|---|---|---|---|---|---|
| H1 | $TSE_{t1} \rightarrow TAM_{t1}$ | 0.037 | 1.354 | 0.06 (*no effect*) | Not supported |
| H2 | $TSE_{t1} \rightarrow IMDM_{t1}$ | 0.024 | 0.521 | 0.02 (*no effect*) | Not supported |
| H3 | $IMDM_{t1} \rightarrow TAM_{t1}$ | 0.831 | 55.112** | 2.48 (*large effect*) | Supported |
| H4 | $IMDM_{t1} \rightarrow TPACK_{t1}$ | 0.436 | 4.756** | 0.21 (*small effect*) | Supported |
| H5 | $TAM_{t1} \rightarrow TPACK_{t1}$ | 0.182 | 2.004* | 0.09 (*small effect*) | Supported |
| H6 | $TPACK_{t1} \rightarrow TPACK_{t2}$ | 0.448 | 5.843** | 0.26 (*medium effect*) | Supported |
| H7 | $TPACK_{t2} \rightarrow IUDM_{t2}$ | 0.459 | 8.259** | 0.37 (*large effect*) | Supported |

TPACKt1, Technological pedagogical content knowledge (Pre); TSEt1, Technological Self-Efficacy (Pre); TAMt1, Technology Acceptance (Pre); IMDMt1, Intrinsic Motivation to use digital media (Pre); TPACKt2, Technological pedagogical content knowledge (Post); IUDMt2, Intention to use digital media (Post).

The research model (see Figure 3) was used to test the variance explanation of the five endogenous variables TAMt1, IMDMt1, TPACKt1, TPACKt2, and IUDMt2 using $R^2$. The coefficient of determination $R^2$ indicates what proportion of the variance in the data of this dependent variable can be explained by the estimated model (Backhaus et al., 2015). It was found that IMDMt1 explains 70.5% of the variance of TAMt1 with an $R^2$ of 0.705 ($p < 0.001$), TAMt1 and IMDMt1 explain the variance of TPACKt1 by 35.7% ($R^2 = 0.357$; $p < 0.001$), and the same applies to TPACKt1 on TPACKt2 ($R^2 = 0.356$ / 35.6%; $p < 0.001$). The extent to which pre-service teachers tend to actually work with digital media and engage in further training (IUDMt2) can be explained to 25.9% by TPACKt2 ($R^2 = 0.259$; $p < 0.001$). Since no significant influence on IMDMt1 could be measured on the basis of TSEt1 (only predictor), TSEt1 does not explain the variance in IMDMt1.

The impact of the gender of the participants on the individual parameters and the development of TPACK was also tested in the model. However, since gender was found not to have any significant influence on the individual parameters, it is not discussed further.

# 4 Discussion

The aim of this study was to evaluate the TPACK development of pre-service science teachers following an intervention in a pedagogical makerspace with respect to personal factors that generally relate, for example, to attitudes and beliefs toward digital media. Moreover, the influence of those factors and TPACK on using digital media in class was examined.

Based on the findings of previous research, a research model was developed that allows technology self-efficacy (TSE), motivation (IMDM), and technology acceptance (TAM) to be assumed as operationalized representatives of personal factors, and thus as predictors of TPACK. Seven hypotheses were formulated to transparently present the relationships among the four constructs before the intervention, the autoregressive relationship of TPACK, and the relationship between the two constructs after the intervention. The results of the analysis support hypotheses H3 to H7 of this study. With regard to t1 (before the intervention), the following findings were inferred:

For TSEt1, no significant influence on TAMt1 and IMDMt1 could be found. H1 and H2 are therefore rejected. That is, confidence in the ability to use the presented technology is neither essential for the motivation to engage with technology, nor does it seem to have an influence on the acceptance of the available technology, e.g., for the creation of prototypes in the context of the project. This is not consistent with findings of Holden and Rada (2011) and Yamamoto (2021), who identified TSE as a significant predictor of TAM. Similarly, the literature points to a strong relationship between TSE and IMDM (Kiyici and DiKkartin Övez, 2021; Lachner et al., 2021; Yamamoto, 2021) that also could not be confirmed by the results of this study. The TSE was estimated relatively high by the students who participated in this study. The variance was also relatively small. Therefore, it could be argued that when a certain level of self-efficacy is reached, other factors, which are still to be identified, are more relevant to influence TAM or IMDM. Another approach was suggested by Joo et al. (2018) who found that TPACK was a prerequisite for self-efficacy to develop. However, they rather investigated the self-efficacy with respect to teaching and the results cannot be generalized easily. Furthermore, the different constructs are measured in different ways, with different scales and with different models. Some of the literature looks at in-service teachers, some at pre-service teachers. Some calculate SEM, as in our study, others base their findings on mean differences, as in t-tests or in ANOVAs. Thus, there is no standardized way of measuring the constructs in question. Different results are therefore not too unexpected and show the need to find a reliable and valid way to measure them (see also Cavanagh and Koehler, 2013).

The investigation of possible interactions between TAM and IMDM was recommended by Lachner et al. (2021), as suitable databases remain insufficient. We found a strong correlation between IMDMt1 and TAMt1 ($r = 0.838$**), confirming H3. The motivation of pre-service teachers to utilize digital technologies depends highly on how the technologies are accepted and assessed as useful and practicable for professional use (70.5%: $R^2 = 0.705$). Both motivation and technology acceptance have an influence on TPACKt1, confirming H4 and H5, but the predictors exhibit only a small effect (see Table 3). Therefore, further factors as predictors for TPACK must be considered.

In line with H6, it was shown that the development of TPACKt2 depended on TPACKt1. This finding suggests that pre-service teachers experience TPACK development on the conscious basis of previous knowledge. However, with 35.6% explained variance, TPACKt1 represents only one of several factors that affect TPACK development. Other factors shaping TPACK-development during work in the pedagogical makerspace were not investigated and thus represent a research desideratum for studies that deal with "TPACKing" in the realm of makerspaces as learning opportunities for pre-service teachers. Nevertheless, pre-service teachers with higher rated TPACK before project work feel that they benefit significantly more than those with lower TPACK.

With regard to t2 (after the intervention), the following results were obtained: As predicted by H7, IUDMt2 is significantly influenced by TPACK with a strong effect. Since this relationship potentially causes an increased engagement with digital media in teaching, it can be assumed that the intentions in turn could be a predictor for TPACK. We did not investigate this effect and neither has it been adequately addressed in the research literature to date. The impact of TPACK on intention was also measured significantly by Liu (2011) and Wangdi et al. (2023), but could not be confirmed by other authors (Joo et al., 2018; Lachner et al., 2021), which according to Lachner et al. (2021) may be attributed to ceiling effects biasing their results.

Although there have been numerous studies dealing with the relationships of the various constructs with each other and with TPACK among pre-service teachers and in-service teachers, there is still disagreement about which factors significantly influence TPACK development. In many studies, TPACK serves as the prerequisite for other factors, like TSE or TAM (e. g., Joo et al., 2018; Thohir et al., 2023; Wangdi et al., 2023). The results of this study take another perspective and sharpen the view on the structure of effects influencing the development of TPACK. This is important to create an effective learning environment in which TPACK can develop optimally. We suggest that a pedagogical the makerspace is such an innovative learning space influencing the development of TPACK. The potential of a pedagogical makerspace lies in the fact that each pre-service teacher can cumulatively build on their personal level of knowledge with their individual previous technological experience and that everyone can obtain support when the lack of TPACK becomes an excessive challenge. Hence, TSE, TAM as well as IMDM could be fostered. At least for IMDM, we could prove that it significantly increased while working in a makerspace (Max et al., 2023), while the relationship with TSE and TAM has been suggested by other studies (e.g., Joo et al., 2018; Thohir et al., 2023; Wangdi et al., 2023).

The learning experiences that pre-service teachers have when tackling the emerging challenges (i.e., designing digitally-supported teaching-learning materials for a specific subject context) are shaped by productive and constructive failure and an open culture of error. On the one hand, the challenges and project goals defined at the beginning can be individually adapted to the learners' level of performance. On the other hand, experts and support materials prevent learners' "complete failure." This appears to be imperative to ensure that related factors (e.g., motivation, technology acceptance, attitudes, beliefs toward digital media) do not negatively impact TPACK development.

## 4.1 Implications for fostering technological pedagogical content knowledge in university education

Our results indicate that pedagogical makerspaces can be regarded as suitable learning environments to develop TPACK, particularly for pre-service teachers who already bring a certain TPACK with them. The level of TPACK at the beginning of the project appears to be an important predictor for TPACK at the end of the project. Similar findings were shown in past research (Zimmermann et al., 2021). However, profound knowledge and technology specific self-efficacy are not needed to perform projects in a makerspace successfully, underlining the approach of equal education (e. g., Heredia and Tan, 2021; Mersand, 2021). Nevertheless, TPACK should be addressed prior to the project work in a pedagogical makerspace during the pre-service teachers' training and extended in a series of learning opportunities.

The psychological transformations that take place while working in a pedagogical makerspace have not been thoroughly investigated. We know little about which personality factors motivate makers, even though there are many obstacles and difficulties during this process. It is important to know which factors can lead to early instances of quitting. These persons need to be supported to keep them going so that they can succeed and improve self-efficacy. Although the present study did not find an effect considering TSE in the SEM, this effect was often reported in other studies. Therefore, this factor should not be neglected. As the participants in our study were already at least in their third year of studying, the level of study progress might vary with TSE as an important influencing factor. Abbitt (2011) found a correlation between TSE and TPACK components that grew stronger from before the test to after the test. The students in this study were at the end of their studies. In a recent study of Zimmermann et al. (2021), the influence of the study progress was integrated in the development of TPACK and self-efficacy. It was found that TSE had more influence in the more advanced students. It is possible that the range of study progress in the study at hand was too large. Further, TSE can also be measured with different instruments; some might be better suited to measure TSE with respect to TPACK competencies. Kiili et al. (2016) for instance validated first their developed scale for measuring technological self-efficacy. This scale was afterward used in an intervention study, while the intervention was video composition, which can be seen as similar to making (creative process with digital media). Approaches like this could be considered for future studies.

It has to be added that working in a pedagogical makerspace is unusual for pre-service science teachers in several ways:

1. They are not familiar with working independently in teams on projects.
2. They are only vaguely familiar with organizing projects over an entire semester.
3. They are often only partially familiar with the technologies necessary for the success of the project.

Although pre-service teachers typically face the challenge of the thoroughly constructivist learning environment of a makerspace, they should be accompanied by support measures. It is therefore appropriate for instructors in a pedagogical makerspace to set a good example and teach with digital media in a project-oriented manner. In many cases, this means that instructors must also first familiarize themselves with the way things work in a pedagogical makerspace.

The intention to use digital media increases with increasing TPACK. For this reason, one important goal in teacher education is to focus on the professionalization of TPACK. However, the concrete implementation of TPACK is not yet well defined and might change dynamically with the fast-paced ongoing progress of technical achievement. Therefore, a continuous derivative in teacher education should be implemented in the curricula and in the personnel planning.

One suggestion was for instance made by Müller et al. (2021) and Grassinger et al. (2022). They clearly argue for project-based learning (for instance in the pedagogical makerspace) and give examples how this can be implemented in the teacher education.

## 4.2 Limitations of the study

Since three out of four cohorts participated in the intervention and evaluation during the COVID pandemic, monitoring of task completion was only possible to a limited extent and, as a consequence, only a portion of the sample took part in the post-intervention evaluation. This was sometimes due to the fact that they were overwhelmed with the change to digital and often asynchronous teaching during COVID, combined with the flood of information and tasks.

On the other hand, the pre-service science teachers were more engaged with the handling and use of digital media in regular courses due to online teaching, which could have influenced the results of the study. The visit to the makerspace had to be booked in advance due to hygiene regulations and was therefore not as flexible as outside the context of the pandemic. As a consequence, pre-service teachers of different working groups could not support each other as it is actually intended for the work in the makerspace and as it is the practice now that the pandemic situation is over and work can be conducted as usual.

As already noted earlier, TPACK was measured by a self-assessment instrument. This is very common in the assessment-research of TPACK, although the (additional) external assessment is recommended by some authors (e.g., Graham et al., 2009; Voogt et al., 2012; Kaplon-Schilis and Lyublinskaya, 2019; Max et al., 2022). To the best of our knowledge, there has never been a SEM carried out in which TPACK has been measured by external assessment. In the present study we could not provide such an analysis, because we had not enough participants in the external assessments for a SEM. All our used constructs are therefore based on self-assessments and should be interpreted as such. The analysis of factors influencing TPACK measured by performance is a research desideratum and should be addressed in the future.

This study investigates the development of TPACK throughout the timespan of one semester. TPACK development however is a long-term process and should accordingly investigated as such. Also the implementation of TPACK in the classroom (hence, in real-life scenarios) should be taken into account in future research.

# 5 Conclusion

The results of this study provide evidence that working in a makerspace supplemented by TPACK-related input is suitable for teaching TPACK to pre-service science teachers. Pre-intervention TPACK is an important predictor of TPACK at the end of the project. IUDM, TAM, TPACKt1, and TPACKt2 correlated with each other. No correlation of technology-specific self-efficacy was found in contrast to other studies (such as Abbitt, 2011; Zimmermann et al., 2021). Thus, neither was the confidence in the ability to use technology essential for the motivation to engage with technology during project work in a pedagogical makerspace, nor did a lack of intuitive usability seem to affect the acceptance of the technology. Intrinsic motivation to use digital media and technology acceptance did influence TPACKt1, allowing TPACKt2 to develop positively (Max et al., 2022, 2023). Increased TPACKt2 at the end of the project had a positive impact on the intention to utilize digital technologies in class.

Our work in the last years indicate that pre-service teachers are willing to engage in project work in the pedagogical makerspace even if their technology-specific self-efficacy is relatively low (see Max et al., 2023). This makes the makerspace an exciting place to learn even for pre-service teachers with lower TPACK. Nevertheless, especially pre-service teachers with higher TPACK before project work increase their TPACK by working in the makerspace (Max et al., 2022). This suggests at least two lines for future research on the use of makerspaces for teaching TPACK: 1. it needs to be clarified which complementary learning opportunities and support pre-service teachers with different prerequisites need to gain the greatest possible benefit from working in the makerspace. In this context, researchers need to consider personality factors that motivate makers. 2. it seems important to investigate what influence project work in a makerspace has on pre-service teachers' conceptions of teaching and whether the makerspace can also function as an accelerator toward more constructivist forms of teaching.

In order to impart TPACK, we consider it necessary to focus on the cumulative professionalization of TPACK and to always pay attention at least to the contextual factors like IMDM and TAM when developing learning.

# Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

# Ethics statement

Ethical approval was not required for the studies involving humans because the study was conducted in agreement with the Declaration of Helsinki (World Medical Association, 2013) and the guidelines set by the local ethics committee. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

# Author contributions

A-LM, HW, and SL contributed equally to conception and design of the study. A-LM collected the data, performed the statistical analysis, and wrote the first draft of the manuscript. SL supervised the statistical analysis. HW and SL revised the manuscript. HW and SL were the project leaders. All authors contributed to the article and approved the submitted version.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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## Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2023.1166018/full#supplementary-material

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