TEACHERS' DIGITAL COMPETENCE IN MODELLING AND EXPERIMENTING WITH AUGMENTED REALITY

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Understanding and creating physical models are a main part of the scientific way of acquiring knowledge and are embedded in curricula. Yet, pupils and teachers often have difficulties with these aspects of science lessons. Augmented Reality (AR) is a digital tool to superimpose virtual visualisations on real backgrounds. It can help linking models and experiments, which usually are not part of the same lesson. Nevertheless, both pre-service and experienced teachers consider their digital teaching competences insufficient.

Within the project diMEx (main project: Digi_Gap), a concept for continuing professional development (CPD) was developed to guide teachers in using AR in secondary school practical physics lessons and promote their digital media and modelling skills. The CPD was pilot tested in 2021 and a second CPD will be carried out in 2022 in the German state of Hesse. To assess the teachers' needs beforehand, data has been gathered from an online questionnaire, including teachers' individual needs for support, their different attitudes towards using digital media, open educational resources (OER), and user-generated content (UGC) in their class. The effectiveness of the CPD will be evaluated by measuring the development of the teachers' modelling competences, their digital skills for modelling AR experiments, and their willingness to use digital tools, especially AR, in school.

Keywords: ICT Enhanced Teaching and Learning, Modelling-based Learning, Teacher Professional Development

THEORETICAL BACKGROUND

Scientific Models and Modelling Competences

Creating and working with models is a main part of acquiring scientific knowledge and is embedded in curricula (German Conference of the Ministers of Education and Cultural Affairs, 2005). These active processes require modelling competences, hence the teachers' ability to work with models and to explain them to pupils. It also means explicitly discussing the construction of models and the necessary idealisations (Winkelmann, 2021). A modelling competence framework has been developed by Upmeier zu Belzen et al. (2019). It consists of three competence levels (models as copies of something, as idealized representations, as a theoretical reconstruction of something), with five aspects of models (the nature of models, multiple models, the purpose of models, testing models, and changing models).

Nevertheless, national and international studies have shown that teachers' and pupils' modelling competences are in need of improvement (Gobert et al., 2011; Nicolaou & Constantinou, 2014; Gilbert & Justi, 2016). Models and their construction are often not further addressed at a secondary school level (Oh & Oh, 2010) and only taught superficially in a positivist manner (Henze et al., 2007). Many pupils find them abstract and difficult, in contrast to experimenting (Winkelmann et al., 2021). Therefore, a training in modelling for teachers is needed, so models are more widely introduced in class.

An idea of combining models and experiments while acquiring scientific knowledge is designed by Teichrew and Erb (2019). Their cycle of knowledge acquisition consists of four topics, arranged in a circle: Pupils identify a phenomenon (1), construct a model for it (2), formulate a hypothesis from that model (3) and test the hypothesis in an experiment (4). To reflect the process, they reverse it: Based on the outcome, they test their hypothesis, review their model and its limits, to characterise the initial phenomenon and explain new experimental outcomes based on their knowledge.

Augmented Reality and AR Experiments

The digital tool Augmented Reality (AR) enables users to add virtual components to a real-world environment by superimposing visual information directly on a real-time camera view (Carmigniani & Furht, 2011). This process is possible via a smartphone or tablet camera, as well as through smartglasses. As Milgram et al. (1994) defined, AR is set in the Reality-Virtuality Continuum, and – instead of immersing the user in a completely virtual environment like VR – augments certain aspects of the real world. When using an AR-capable mobile device, applications can either access the internal sensors (e.g., camera, gyroscope, accelerometer) to detect a surface (markerless), or react to visual markers and triggers with a marker-based software (Johnson et al., 2010).

AR technology can be used in many fields, such as advertising, gaming, or navigation, but also in research and medicine (Carmigniani & Furht, 2011). In the last few years, AR has become more and more prominent in various contexts, including education (Altınpulluk, 2019). As a digital learning tool, AR enables linking an abstract concept to a real-life context, making it easier to understand (Bloxham, 2014). A promising example from physics class is overlaying real-life experiments with virtual, dynamic 3D models created by using *GeoGebra 3D Calculator*. This free browser and mobile app allows placing 3D objects modelled in *GeoGebra* (geogebra.org/3d) via a device's camera on any surface and adjusting them to the real experiment (Teichrew & Erb, 2020). This way, usually unobservable (micro- or macroscopic) objects with an explanatory power enrich the traditional classroom experiments by linking and comparing models and experiments in real time (see figure 1).

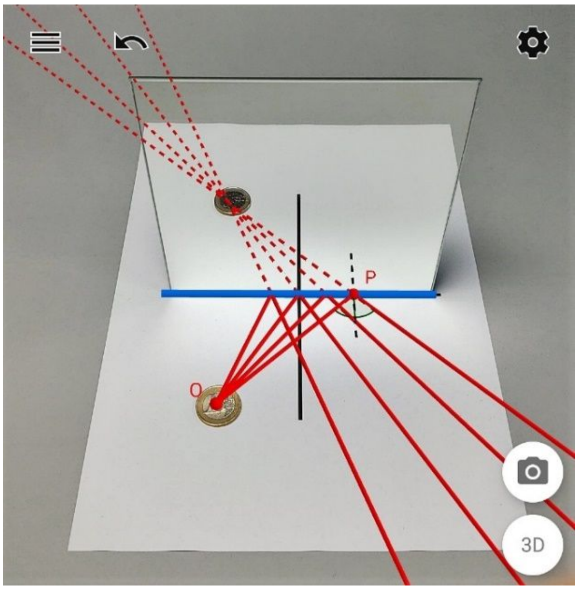

Figure 31. Image formation behind a real-life plane mirror with modelled rays of light.

Digital (Modelling) Competences for AR Experiments

In modern society, digital skills and competences are necessary for many domains of life. With digital media being an essential part of their everyday life, young people grow up as digital natives (Prensky, 2001). In school, the significance of digital media has grown, too, and teachers need to handle them competently. Therefore, digital competences have often been defined and structured in various competence frameworks, for example with the interdisciplinary TPACK framework (Mishra & Koehler, 2006) and the DigCompEdu reference framework by the European Commission (2017). For German-speaking countries, Becker et al. (2020) created the DiKoLAN framework, which aims at student teachers of natural sciences. However, those frameworks cover many aspects of digital competences that teachers should be trained in. Therefore, the presented project will concentrate specifically on those digital competences that are needed for implementing AR experiments in physics lessons. These include operating the software (*GeoGebra*) and hardware (tablets and smartphones), but primarily using the digital tool AR purposefully in the classroom, which is a combination of both technological and content knowledge and its didactic implementation (Guillén-Gámez et al., 2020). In order to promote modelling competences with AR experiments, these particular digital competences are needed. Both are necessary and their overlap must be trained in a CPD.

Successful Continued Professional Development

After the university studies and the practical internship in schools, continued professional development (CPD) marks the third phase of teacher training. It enables in-service teachers to face new challenges of their profession and meet further requirements while also impacting pupils' learning success (Polly et al., 2015). However, an effective CPD needs to fulfil specific requirements (Lipowsky & Rzejak, 2015), among them a longer period of sessions, the combination of input, practice and reflection phases, a focus on subject-specific learning needs, and providing helpful feedback to the teachers. Furthermore, integrating open educational resources (OER) in a CPD can positively influence the innovative use of teaching material – both searching for it and designing their own OER content (Karunanayaka & Naidu, 2017).

STUDY DESIGN

The aim of the interdisciplinary project "Digi_Gap – Bridging digital gaps in teacher education", funded by the German Federal Ministry of Education and Research, is to locate, analyse, and close digital gaps related to didactic, organisational, individual, and technological factors in educational processes (Academy for Educational Research and Teacher Training, n.d.). Within the subproject "diMEx – Digital Competences in Modelling and Experimenting" a CPD concept for implementing Augmented Reality experiments in physics classes is developed, conducted, and evaluated. The goal is to increase secondary school physics teachers' digital competences regarding dynamic 3D models. Furthermore, it investigates how a combination of real experiments with digital models in an AR learning environment can lead to a better understanding of models and a more frequent explicit use of them in physics classes, by reflecting the construction process of models and underlying idealisations. The following research questions are therefore addressed:

(1) Does a CPD about using AR experiments in physics lessons improve the teachers' modelling competence?
(2) Can the CPD improve the teachers' digital competences needed for creating dynamic 3D models?

(3) How does the teachers' willingness to use digital tools in class change by attending the CPD?

Preliminary Study: Teachers' Need for Professional Development

To develop the CPD, a preliminary study was conducted in summer 2020 (Freese et al., 2021). With an online questionnaire, the attitudes and experiences of secondary school physics teachers (n = 81) regarding the use of digital tools in class were examined. It contained seven Likert items and two additional open questions about a definition of and experiences with AR. Twelve applications of analogue and digital tools were presented, for which the teachers had to report if and how they had used them in class. Using scales by Vogelsang et al. (2018), the Likert items explored the attitudes and motivation for using digital media in lessons, the teachers' skills, and the availability of digital devices in school. Furthermore, the teachers' attitudes towards open educational resources (OER), created by internet users (user-generated content, UGC), were examined.

As the results of the preliminary study show, the teachers' experience in the use of (digital) media and tools in physics lessons is mainly limited to well-known applications, like photos and videos, or static drawings and sketches. The field of AR and VR calls for further training, as there is a lack of knowledge about the possible use and suitable tools. Only 15% of the teachers consider themselves able to use AR technology in their lessons. The open question to define AR was answered by 38 teachers, of which half of them match the definition given in Teichrew and Erb (2020). In the feedback questionnaire, the teachers expressed the wish for a CPD about digital tools which also takes care of beginners in this field. Furthermore, as expected, the lack of technical equipment at schools is criticised by almost 80% of the teachers.

Regarding OER and UGC, there is a high willingness (90%) on the teachers' part to share self-designed teaching and learning material on the internet. However, 83% have not yet made their material available online. Some teachers are concerned that the current OER teaching material has often undergone no quality control and cannot be used in all learning groups. In conclusion, the further training concept will include all school forms for networking and exchanging internally differentiated teaching material.

Main Study: A Concept for Continuing Professional Development (CPD)

Based on the preliminary survey results, a CPD concept for secondary physics teachers was developed. In five sessions over several months, the teachers learn to create AR experiments with the modelling software *GeoGebra* and implement them in their lessons. The CPD is based on the TPACK framework (Mishra & Koehler, 2006). It starts with the basic principles of models as a part of acquiring scientific knowledge, after which the teachers learn to use the software and platform *GeoGebra*. This includes searching for suitable existing 3D models on the platform's OER database and modifying them for their lessons. Subsequently, the teachers create their own models and enhance them with short info texts, images, and open or multiple-choice questions. Those dynamic teaching materials can later be uploaded themselves as OER on the *GeoGebra* platform, which allows them to be shared and reused by others. The focus of the input and workshop phase is not on the correct use of mobile devices like tablets, but on their didactically appropriate implementation with self-developed AR experiments. A self-study module and interviews accompany this practical phase. Lastly, the teachers reflect on the implementation with the whole group and their AR experiments are evaluated (peer and expert feedback).

Regarding content, the teachers can choose the physical phenomena they want to cover in their AR experiment – depending on what classes they teach and what subjects are in the curriculum. The *GeoGebra* OER database contains some of the organisers' prepared models, e.g., the subject areas mechanics, electricity, and optics (Erb & Teichrew, 2020; Teichrew & Erb, 2020; Teichrew et al., 2019).

The CPD was pilot tested from May to July 2021 at the University of Education Schwäbisch Gmünd, Germany. Due to the pandemic situation, only five secondary school teachers participated, and the first two sessions had to be held online via video conferencing. In the first session, in addition to a theoretical introduction to AR experiments, the teachers were trained to use *GeoGebra* on AR-ready tablets. A few already had some experiences with *GeoGebra* from other contexts, like mathematics classes. Between each of the five input and development sessions, the teachers had to use AR experiments in their lessons – starting with AR experiments prepared by the organisers, up to their own created models. Every following session, they would reflect on and discuss their experiences to enhance their models for the subsequent classroom use.

Some aspects of the pilot tested CPD concept were adapted after evaluating the results and the teachers' feedback. As the first two online video sessions did not reach the quality of on-site sessions, the main CPD was planned to take place exclusively at premises of the Goethe University Frankfurt, Germany. Because of the pandemic, the sessions were held in external conference rooms, with an elaborate hygienic concept and split groups. As the pilot testing took place while the schools were still closed, some teachers had difficulties implementing their AR experiments in remote learning. Therefore, the main CPD was supplemented by screen-sharing and online teaching tutorials. Sharing the screen with a projector is also a great way to make the AR experiment accessible to the class when there aren't enough devices for students to practice independently.

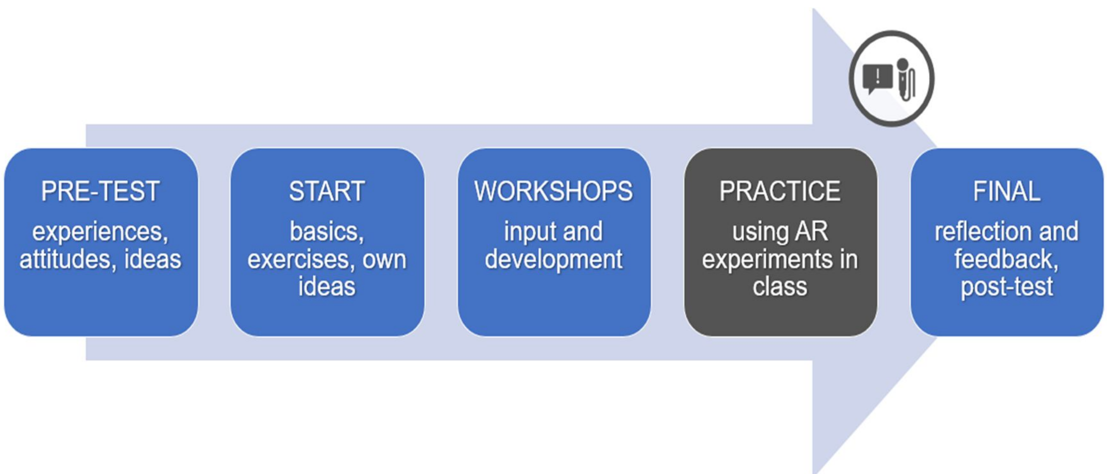

Figure 32. Structure of the main CPD.

The most noticeable edit was the structure of the input and implementation phases (see figure 2). With an overall duration of six months, the main CPD started in September 2021 by providing the teachers with basic information on AR experiments, exercises, and collecting their ideas on possible subjects. It continued with three consecutive workshop sessions to develop the *GeoGebra* 3D model. During the three-month practice phase (December 2021 to March 2022), the teachers had enough time to finish their model and to implement the AR experiment in their lessons. However, they have been accompanied by the organisers and were given online self-study modules written by the organisers, with detailed manuals on all aspects of *GeoGebra* models and AR experiments. The teachers have also been requested to participate voluntarily in semi-structured interviews in which they can give individual feedback.

The final reflection and feedback session is scheduled for March 2022, before the schools' graduation exams. The teachers' experiences with the AR experiments are presented and discussed in the group. They can exchange advice, aims and conditions for a successful implementation, and are furthermore given expert feedback by the organisers. The AR experiments are evaluated according to a rating system (see below).

Measuring Instruments

To answer the three research questions (see above), the pilot test of the CPD was evaluated with a pre-post survey, questionnaires at several times of measurement, and semi-structured interviews. For the main CPD, a rating system has been developed which focuses on the digital competences needed for modelling the AR experiments. It is based on the TPACK framework and has five variables which are validated with a template filled in by the teachers after implementing their AR experiment in class.

Table 1 gives an overview of the measuring instruments for research question (1), regarding the teachers' modelling competence.

Table 44. Measuring instruments for modelling competence.

Variable	Method	Basic instrument
Teachers' understanding of scientific models	Open questions	Windschitl & Thompson (2006)
Didactical handling of models in class	Closed-ended vignettes	Billion-Kramer et al. (2020)
Willingness to use models explicitly in the lessons	Self-assessment (post-test and follow-up)	Semi-structured interview, own design

Research question (2), regarding the digital competences needed for modelling dynamic 3D models, will be answered with the rating system shown in table 2. The AR experiments are evaluated by expert raters based on a profile template the teachers fill out after their lesson. It includes a learning objective, a screenshot of the AR experiment, and the link to the original *GeoGebra* model. In a follow-up inquiry, the teachers will be interviewed approximately six months after the CPD about their current use of digital tools, and their self-assessed ability to use AR experiments in class.

Table 45. Measuring instruments for digital competences.

Variable	Description of the highest competence level
Digital skills (TK)	The teachers can construct and operate their own dynamic 3D model from scratch and open it on a mobile device using the AR mode.
Content-related design (TCK)	The physical content of the dynamic model is accurate and the relations between all variables are transparent.
Didactical design (TCK)	The dynamic model is visually appealing: the user's view has been reduced to the relevant variables and only contains necessary labels. The list of algebraic commands has been properly shortened (auxiliary objects hidden). The model can be operated intuitively.
Didactical use of AR experiments (TPK)	The teachers have phrased an appropriate learning objective for the implementation of the AR experiment which matches its complexity and underlines the profitable character of this technology.
Digital modelling competence (TPACK)	By being augmented by the virtual contents, the real experiment is enhanced so that the underlying model can be easier understood. It is clear which parts of the phenomenon are represented by real experiment materials or by virtual objects (Teichrew & Erb, 2020).

Table 3 shows the instruments used for answering research question (3) regarding the teachers' willingness to use digital tools, such as AR, in class.

Table 46. Measuring instruments for willingness to use digital tools.

Variable	Method	Basic instrument
Teachers' attitudes towards using digital tools	Likert scales	Vogelsang et al. (2019)
Teachers' experiences with *GeoGebra*	Likert scales and open questions	Own design
Willingness to use digital tools, such as AR experiments, in class	Self-assessment (follow-up)	Semi-structured interview, own design

EXPECTED RESULTS AND CONCLUSIONS

After the CPD, we expect the teachers' modelling competence to improve due to reflecting the construction process of scientific models and the idealisations that go with them. This means a higher understanding of models to acquire scientific knowledge and a more confident didactical handling of them in class. This leads to an increased willingness of the teachers to explicitly use models and teach their construction process in their lessons.

The digital competences needed for modelling dynamic 3D models are expected to improve thanks to the instructed handling of the software *GeoGebra* and the associated mobile app, as well as the thoroughly prepared implementation of the AR experiments in class. This competence's highest level (TPACK) requires successful modelling, an appropriate content-related and didactical design of the model and teaching material, and a purposeful use of the model in class.

As a result of the improved digital and modelling competences, the teachers' willingness to include digital tools (especially AR) in their physics lessons is expected to increase. In general, we expect that the CPD will help make digital teaching and learning contexts more accessible. Teachers will be able to implement AR experiments particularly more effectively in schools.

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