IMPROVING STUDENTS’ TPACK THROUGH LEARNING LABS: THE IMPLEMENTATION OF ICHEMLAB AND STEAM MAKERSPACE

S. Lukas, W. Müller, J. Huwer, C. Drüke-Noe, I. Koppel, S. Rebholz, J. Stratmann, F. Theilmann, H. Weitzel

University of Education Weingarten (GERMANY)

Abstract

Digital transformation impacts almost every aspect of life, and it is linked to a comprehensive societal transformation. It is broadly accepted that future citizens require substantial information and media literacy skills, not only to participate effectively in societal and political processes, but also to succeed in their professional life. Schools are therefore obliged to equip students with necessary media competencies. Standards for media literacy of future citizens have been proposed (e.g. [1]), and corresponding elements are being integrated in school curricula worldwide. Consequently, prospective teachers need to be provided not only with suitable media literacy, but also with adequate pedagogical competencies to teach students necessary knowledge and skills. Furthermore, school is expected to reflect the digitized environment of today’s students and to adequately equip students with necessities for lifelong learning. This requires teachers to prepare students with the application of methods of digital learning which are typically linked with selfGuided learning. The TPACK model (e.g. [2]) depicts the different competencies that today’s teachers need. General standards which are related to media literacy and the application of digital media in the classroom, have been proposed for teacher education ([3]). However, due to rigid state regulations, complex organizational situations and the diversity of stakeholders involved in teacher education, the integration of corresponding elements into existing teacher education programmes is difficult in many cases. Therefore, very often these programmes lack behind the necessities outlined above. Furthermore, existing standards do not sufficiently recognize the specific aspects, potentials and methodologies of teaching media literacy and technology-based learning in context-specific subject areas.

In this paper we present an approach to integrate teaching media literacy, media pedagogy and technological-pedagogical content knowledge into an existing teacher education programme. This programme is consistently based on the concept of learning labs. We specifically designed two labs, both linked to Science, Technology, Engineering, Art and Mathematics (STEAM) education. The approach is based on two labs and learning environments, the so-called iChemLab and the STEAM Makerspace, which are both intertwined with and integrated into the programme. These labs aim to provide prospective teachers with media-related teaching approaches. In these labs students can design, implement and evaluate digital learning material and thus foster their TPACK.

The iChemLab is based on the concept of a German Schuelerlabor (pupils’ laboratory) in which pupils use the method of inquiry-based learning. In this lab, students supervise the learning progress of pupils in digitally enhanced learning scenarios. Simultaneously, students learn to apply digital media effectively and to provide support ([4]). The STEAM Makerspace is based on the idea of makerspaces but has a strong pedagogical focus (e.g., [5]). It is based on constructivism and thus an approach to learning as an active process that is most successful when experiencing and creating a mental construct of one’s own and/or also a physical construct of the learning material. Therefore, based on pedagogical and psychological theories this lab provides the opportunity to design, implement and evaluate digital learning media to be applied in teaching situations.

Keywords: TPACK, learning labs, makerspace, STEAM, teacher education.

1 INTRODUCTION

Digital transformation impacts almost every aspect of life and it is linked to a comprehensive societal transformation. It is broadly accepted that future citizens will substantially need information and media literacy to not only participate effectively in societal and political processes but also to succeed in their professional life. Furthermore, the constantly increasing speed of innovation requires citizens to maintain and further develop their knowledge and skills continually and independently in terms of lifelong learning. Corresponding challenges have been echoed in various national and international white papers and agendas (e.g., [1], [6]). In the future, citizens’ crucial learning activities will be characterized...
by self-guidance, cooperation and the comprehensive use of digital learning material as well as the use of information and communication technologies. As a result, from an early stage in school on students have to be equipped not only with adequate information and media literacy, but also with the abilities to apply modern information technology to find helpful digital information and learning material and utilize these to advance their competencies and skills effectively, either alone or in collaborative scenarios. Schools are therefore challenged not only to adapt their curricula, but also to rethink and redesign their teaching methodologies in general.

As a consequence, standards for media literacy of future citizens have already been proposed (e.g. [1], [3]) and corresponding elements have been integrated into school curricula worldwide. However, schools frequently struggle to take up on these challenges and changed objectives (e.g. [7]). Various international studies show that students may not acquire the necessary skills and competencies at school (e.g. [8]). While in many cases schools’ poor digital infrastructure and media equipment clearly contribute to this, a major problem is that digital media is not sufficiently integrated into learning and teaching activities by teachers, and the full potential of digital learning is not exploited ([9], [10]). Major reasons for this condition are to be found in the lack of media literacy and self-efficacy of teachers and a resulting lack of acceptance of digital media and information technology in learning activities (e.g. [9], [11], [12]). These findings indicate that teacher education requires novel and more comprehensive approaches to equip teachers with necessary competencies to be confident in the integration of digital media into learning activities and to effectively integrate media literacy in the classroom.

The TPACK model ([2], [13], [14]) details fundamental competencies required by teachers in this context. TPACK stands for Technological Pedagogical Content Knowledge and is based on the concept of PCK (Pedagogic Content Knowledge) by Shulman [15]. It refers to a conglomerate of knowledge facets that characterize good teachers. Technology knowledge (TK) comprises strategies to support digital teaching. As examples, [14] lists the ability to use and foster standard software and by staying up-to-date with respect to evolving technologies. Pedagogic knowledge (PK) includes considering methods and tools to teach, processes of learning and goals and values of the content of teaching. It is based on a transfer from the knowledge of cognitive, social and developmental theories to the application in the classroom. Content knowledge (CK) refers to the expertise with respect to the specific discipline/subject that is taught. Technological, Pedagogical and Content knowledge are are closely related to each other and display intersections. Technological Content Knowledge (TCK) links technology and content knowledge and it comprises knowledge of how the content of a specific subject is or can be influenced by technology and how technology might support the progress of a specific subject. Koehler and Mishra define it as the “understanding of the manner in which technology and content influence and constrain one another” ([2], pp 65). PCK comprises the knowledge how the content of a specific subject can be taught most effectively and successfully and it therefore constitutes the core of typical teacher education curricula. TPACK is the proficiency of differentiating and anticipating how technologies can be used in pedagogical contexts and how they will affect and change the learning process. However, TPACK does not contain all knowledge teachers should have with respect to digital media. It does not explicitly depict competencies related to conveying information literacy and media literacy. Also subject-specific approaches and methods with respect to media-supported didactic strategies, their implementation and their general use are typically not sufficiently detailed and distinguished from general approaches of technology-based learning. By now, in various subject fields very specific media-based approaches have been developed, which cannot easily be transferred to other domains. Dynamic Geometry Systems and their application to education represent a good example for this, constituting a very specific approach to the field of Mathematics which is linked to very characteristic and specific instructional approaches ([16]).

Different aspects of TPACK, like media literacy instruction and often also subject-specific approaches to media-based instruction, are not sufficiently covered in teacher education. Thus, prospective teachers need to be better prepared for these affordances in teaching. Especially technological knowledge, which is related to general “media competence”, is not comprehensively taught in teacher education. This is due to the difficulty to integrate corresponding components of media literacy and media pedagogy into existing curricula, given both the complexity of this task and the diversity of stakeholders involved. Concerning the complexity of this task, a good definition and containment of “technological knowledge” or “media competence” is needed to determine educational objectives in the teacher education curriculum. There are quite different stakeholders involved: these are not only the students with different levels of previous knowledge but also the lecturers with different levels of technological knowledge. Additionally, the executive board at a university and its attitude towards the integration of technological knowledge in the curriculum, as well as the associated political ministry are to be named here.
In this article, we present part of the project “TPACK 4.0: interdisciplinary, pragmatic, research-based advancement of media-didactic competencies of teachers”. This project is funded by the Ministry of Science, Research and Arts. It is advanced by the executive board of our university and already involves two of the stakeholders named above. The part presented here describes the implementation of two learning labs at the University of Education Weingarten: one is the iChemLab and the second is the STEAM Makerspace. Both labs are mainly linked to Science, Technology, Engineering, Art and Mathematics (STEAM) education. The so-called iChemLab and the STEAM Makerspace are intertwined with and integrated into the programme. After clarifying the use of learning labs on the basis of learning theories, we present the concepts, the implementation and realization of the iChemLab and the STEAM Makerspace and how they are integrated in the entire program.

2 THEORETICAL BACKGROUND

Constructivist learning theories, which can (amongst others) be traced back to the works of Jean Piaget and Lev Vygotsky, take a strong relation between the (active) learner and his/her learning environment into account (e.g. [17], [18]). In constructivist theories, cognitive structures can evolve when the environment provides the opportunity to act and explore. In an interactive environment, questions arise and keep the learner active, due to his/her self-organizing tendency. Learning is seen as a process rather than a mere result. People construct knowledge and proficiency by making experiences, and in the course of active problem solving more effective strategies are adopted (e.g. [19]). Communication and social interaction at eye-level with co-learners and teachers are seen as important facets to support the learning process. According to modern educational approaches, appropriate learning environments provide more effective learning processes. Bada ([17]) contrasts traditional classrooms with constructivist classrooms. Following characteristics constitute the latter:

- Materials include adaptable material
- Students’ questions and interests are not only welcome but also actively pursued in the curriculum
- Learning is interactive and it relies on the students’ previous knowledge
- The teachers’ role is interactive
- A teacher communicates by means of dialogues and supports students to construct their knowledge
- Assessment can include students’ work, opinions and observations as well as tests
- Knowledge is considered to be dynamic
- Students work primarily in groups

The term "makerspace" is used for a wide variety of settings dedicated to the creative use of knowledge. "A makerspace is a collaborative work space inside a school, library or separate public/private facility for making, learning, exploring and sharing that uses high tech to no tech tools“ ([20]) and in which products can be developed, manufactured and also repaired. Working in a makerspace aims at facilitating (interdisciplinary) collaborations that promote the development, implementation and testing of new ideas and the further training of its participants. Makerspaces are often located in engineering sciences and target the learning of object design (CAD), manufacturing techniques (e.g. 3D printing, laser cutting, but also electronic sewing and embroidering machines), production processes or rapid prototyping ([12]).

Makerspaces have the potential to serve as an interactive environment in which students are able to learn by doing, cooperate and take an active part in the learning process. At the same time, the teacher is rather a learning mentor and learning takes place in a self-directed as well as self-organized manner, and thus it meets the prerequisites of constructive learning (e.g. [21]). Consequently, educational makerspaces have become very popular in the last couple of years. In 2014, more than 100 makerspaces worldwide were listed on the website of https://makerspaces.make.co/ ([22]), today there are more than 800 (attention should be drawn to the fact that these are only the registered makerspaces and not necessarily educational ones). Makerspaces are the product of the “maker movement” that has gained impetus with the new digital technologies. As co-founder of the maker movement, Mark Hatch and Neil Gershenfeld are often mentioned (e.g. [11], [12]). With the digital transformation, objects cannot only be “made” but also be shared. Makers now easily exchange their approaches, manuals, tools and material by digital communication. Halverson and Sheridan name three
key characteristics of the maker movement: “the use of digital desktop tools, a cultural norm of sharing designs and collaborating online, and the use of common design standards to facilitate sharing and fast iteration” ([22], pp. 496). There is also a general agreement that a democratizing nature underlies the maker movement: this is especially evident as it is easily accessible for everyone and material can be (re-)used cheaply and is easy to obtain. Hence, the new awareness of economising our natural resources, sustainability and fair trade which accompanies the growing globalisation is in line with the ideas and acting of the maker movement.

With respect to education, learning-by-doing or learning-by-making had been popular and discussed before the new maker movement arose. But with the possibilities of new technologies and the maker movement, which led to the implementation of the first makerspaces, learning-by-making concepts have been enriched. As computers and internet access are widely available, solutions for problems can be researched and finished products can be shared easily. Probably due to the technological equipment, makerspaces with respect to education have mainly been associated with the traditional Science, Technology, Engineering, Art and Mathematics (STEAM) subjects. However, in our opinion also the Social and Humanities subjects (and actually many others) can profit from the integration of “making” in education.

So-called “Schuelerlabore” are out-of-school, non-formal learning environments for students at school. These laboratories (casually translated as ‘school lab’ or ‘out-of-school labs’) were developed in Germany after the so-called PISA shock. Mostly these Schuelerlabors are found at universities and other research institutions, but sometimes also in private environments, like e.g. the “Schülerforschungszentrum” (Young Research Center, YRC) in Hamburg (Germany).

One of the primary goals of Schuelerlabors lies in promoting the school students’ interest in and understanding of science, technology, engineering and mathematics. At the same time, they aim at raising motivation and, if possible, also bring about cognitive effects. Although this is primarily the social task of the schools, the Schuelerlabors are able to complement certain aspects of education (“Bildung”) ([24]). For example, Hopkins & McKeown revealed that formal school education needs to be improved when it comes to Education for Sustainable Development (ESD) ([25]). This improvement could be the enrichment of formal school education with non-formal education in Schuelerlabors ([26], [27]). The second of the primary goals is to promote young talent for STEM professions and STEM study courses and thus take on a societal and economic task. To make sure these primary goals are achieved, Haupt and colleagues ([28]) defined certain room and time requirements for all types of Schuelerlabors: The laboratory(-room) is operated as a Schuelerlabor at a minimum of 20 days per year, the main focus lies on hands-on experimentation, research-based-learning or inquiry-based learning and there is expert staff for mentoring the school students in being STEM scientists ([4]).

There are several categories of Schuelerlabors. One of the most important categories is the classical Schuelerlabor, which is visited by whole school classes, because the experiments in a Schuelerlabor are closely related to the school curriculum or at least fit to a topic in class ([28]). The teaching-learning-Schuelerlabor is another category. This type of laboratory can only be found at universities that train teachers. In this version of Schuelerlabor, STEM-students learn to support school students in small groups. In terms of “conventional” STEM Education, teacher-students have also the opportunity to develop, test and evaluate “mini-learning-modules” (e.g. experimental courses) with the supervision of educational/science experts in the Schuelerlabor.

Following constructivist learning approaches and being convinced of the benefit that makerspaces and learning labs can add to academic education, we implement a makerspace and a Schuelerlabor at the University of Education Weingarten. The Schuelerlabor iChemLab focuses on Chemistry studies and school students. The conception of the STEAM Makerspace is less dedicated to only one specific subject, although the focus lies on STEAM education. Both learning labs do not only have the goal to be used with respect to gain subject-specific competencies, but also to gain general technical competencies across subjects, like proposed by TK and TPK in the TPACK model and subject specific technical competencies, i.e. TPACK. The learning objectives are as follows:

- Subject-specific competencies
- General technical competencies
- Subject-specific pedagogical technological competencies
- Technological Pedagogical Content Knowledge
The following section discusses the implementation of the two learning labs as well as their integration into the curriculum and working plan of our project.

3 REALIZATION

3.1 iChemLab

The Schuelerlabor iChemLab is a classical Schuelerlabor and a teaching-learning lab as defined by Haupt et al. ([23]). There is also a need for a new category when it comes to promoting media literacy. As a teaching-learning Schuelerlabor, the students learn in an accompanying class how to supervise and encourage students in inquiry-based learning. First, theoretical foundations of Inquiry-Based Learning are acquired. Thereafter, concrete experiments will be discussed and how to support students individually, e.g. with step-by-step help to realize degrees of confirmation inquiry, structured inquiry, guided inquiry and open inquiry within a class ([29]). For experimentation, the school students have access to a laboratory room with chemicals and other equipment in order to do their research.

But we need another category of a Schuelerlabor when it comes to promote competencies in the digital world. In Germany, "competencies in the digital world" created a framework in which media literacy should be taught. A key aspect of this paper is that media literacy is not acquired as a separate subject but as a spiral curriculum in each subject.

It is a challenge for teachers and universities that STEM students must now acquire the necessary skills to teach media literacy. The national working group "Basic competences in STEM teacher training" has defined the following areas of expertise for the training of STEM students, although these are only partially covered in TPACK:

- Basic technical skills
- Documentation
- Presentation
- Collaboration
- Research and evaluation
- Data Logging
- Data Processing
- Simulation and modeling

In chemistry, all of these areas of competence play a separate role. Chemistry is an experimental subject in which the handling of chemicals (hazardous substances) requires special training on how to promote media literacy in experimentation.

Therefore, our concept of the iChemLab envisages that the teacher students in the teaching and learning laboratory acquire their first competencies in the protected area of the university. The students also learn the theory of inquiry-based learning and media literacy in chemistry lessons. Thereafter, the individual coaching is practiced and reflected on the basis of concrete best practices.

In the next step, the students themselves should design small learning arrangements that focus on both inquiry-based learning and media literacy. These learning arrangements are not only designed, but also tested and evaluated in the course of bachelor's or master's theses. For this purpose, the students have access to a supplementary area of the student laboratory, the "Genius Lounge". This place serves as a place of creative didactic creation.

The Genius Lounge receives:

- Technical and chemical equipment necessary to develop digital learning offerings (e.g. tablets, laptops, camera, digital data loggers, photo chamber, a digestivum, ...)
- A selection of appropriate presentation media for collaborative work (e.g., whiteboard, active board, flipchart, ...)
- Self-learning material with different tutorials (blended learning), The possibility to book an expert to provide individual, personal assistance in the realization of one’s own project (lecturers or students of the higher semester)
The learning scenarios are structured according to the didactic functions of digital media in chemistry lessons: learning-tool, learning companion and experimental tool. As an experimental tool, ICT offer the possibility to support experiments, for example in the form of direct measurement data acquisition, which is relevant in the natural sciences ([30]). As a learning tool, ICT can support the cognitive learning process in concrete situations, for example through visualization ([32]). If the ICT is used as a learning companion, it enriches the cognitive learning process over a longer period of time and ideally combines formal, non-formal and informal learning. An example of such a learning companion are Multitouch Learning books ([31]).

3.2 STEAM Makerspace

Based on the TPACK model, the educational makerspace of the University of Education Weingarten aims at the teaching of media competence and TPACK of prospective STEAM teachers. Hence, we are developing our makerspace as creative digital space in line with the federal strategy for the digitalization of teacher education in Germany ([33]).

The work in the pedagogical makerspace pursues four main goals: Students learn 1. to use and produce media for teaching using digital or digitally controlled devices. These include the production of learning videos, animations or simulations, the construction of virtual or physical 3D models, the usage of microcontrollers for measuring environmental or physical data, the programming of robots representing biological or technical systems, 2. to plan and carry out lessons for working with (school) students in a makerspace e.g. modeled on problem-based learning, 3. to evaluate third-party or self-produced media for their learning effectiveness in class and optimize media on the basis of evaluation results. 4. to cooperate and collaborate with students from other disciplines (e.g. computer science, game design, etc.) in the creation of media. This last goal serves in particular to show teacher students the relevance of collaboration for their later professional life as a teacher. In a constructivist sense, all projects and collaborations realized in our pedagogic makerspace are based on the students' own questions, who seek partners for the implementation of their projects.

In order to achieve these goals, the makerspace is divided into three sub-areas. In one room there is a video laboratory with a green screen and video editing stations. Different camera systems of varying complexity (iPad, SLR, high-speed cameras) and video editing systems (iMovie, Finalcut) allow a fast and less complex introduction to video creation as well as professionalization for interested students. A second room is equipped with robots (Arduino, Lego Mindstorms), 3D printers, microcontrollers and much more. The framework for the equipment of the makerspace is set by the usability of the devices or the products created for higher education or classroom. Our educational makerspace is complemented by open seating areas that invite students to jointly develop ideas and offer them workspaces for their projects.

In their work in our makerspace, the students are supported by peers, by staff members who coordinate the work and machines and by a database of learning videos which gives the students access to basic technical skills or operating procedures (how do I use a green screen, how do I make a 3D printer print, etc.). We are currently working on building this database with learning videos. The students will also be involved in this process.

The students' work in the makerspace is integrated curricularly into teacher education at our university by lecturers from different subjects holding classes in the makerspace or delivering courses in the form of projects that can be worked on. For this reason, the infrastructure of our makerspace is accessible both for students and for teachers of the university at all time. Additionally, the curricula of the STEAM disciplines encourage projects for Master students addressing individual TPACK or media competencies.

Moreover, the idea of collaboration is exemplified by joint lectures by teachers from different disciplines. Activities here include cooperative courses which combine mathematics and physics with projects on stochastic processes like random walks due to Brownian motion (which are filmed and analyzed by students), analyses of meteorological data obtained from self-built weather stations, cooperative courses between biology and engineering aiming at constructing and optimizing 3D-models. Other activities also rely on criteria for planning, realizing and reflecting experiments. For example in statistics students collect bivariate data and develop mathematical models to describe the relation of these data mathematically.
4 CONCLUSIONS

With the iChemLab and the educational makerspace, the University of Education Weingarten is creating two places where central requirements for the qualification of prospective teachers for digital transformation can be met. The two learning labs provide the technical infrastructure needed to impart media skills and TPACK as part of teacher education. In addition, digital education will be integrated into the curriculum in a theoretically based and systematic way and thus contribute to a comprehensive media competence of prospective teachers, which comprises not only the production and use of digital learning media but also the implementation and evaluation of teaching. The curricular collaboration between peers (students with students, university lecturers with university lecturers) from different disciplines creates creative spaces that can also contribute to the further development of teaching concepts and promote digital transformation. The cooperation with surrounding schools also helps to evaluate the effectiveness of the ideas, concepts and media developed in the learning laboratories iChemLab and makerspace and at the same time transfers innovative ideas and teaching concepts to the schools.

The realization and implementation of the two learning labs are accompanied by formative and summative scientific evaluation. One goal of the evaluation process is to analyze the progress of technical and media competences of the students as well as of the academics. Here we differentiate between general technical/media competencies and subject-specific media competencies. The progress is not only evaluated by temporal comparison (pre- and posttest), but also by investigating highly comparable groups (i.e., students, who have attended a course with TPACK as learning goal, vs. students who have attended a course in the same subject, preferably with the same lecturer, without having TPACK as learning goal). We will use quantitative as well as qualitative approaches and closely relate to TPACK assessment instruments (e.g., [34]).

To sum up, in this article, we present an approach to include TPACK as learning goal in the curriculum of teacher and education studies. This aim is supported by the realization and implementation of two learning labs, the iChemLab and the STEAM makerspace. The process of this activity is supervised and evaluated scientifically. New insights of the role of academic courses on the basis of constructivist learning theories with the focus of TPACK as well as setscrews, affecting the use of digital media in the classroom by pre-service teachers are expected.

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