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Self-efficacy – the final obstacle on our way to teaching mathematics with technology?

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Despite the potential of digital technology to enhance the learning of mathematics the use of graphing tools with or without computer algebra systems (CAS) remains low. For this reason, there is a need to identify and understand factors that lead to greater technology uptake. In this quantitative study with 198 upper secondary in-service teachers from Germany the relation between self-efficacy beliefs and frequency of technology use in the mathematics classroom is examined. Results show that higher self-efficacy beliefs are strongly associated with a more frequent use of technology. Based on the results, recommendations for teacher education are given.

Keywords: Self-efficacy, technology, teacher-education, graphing calculators, professional development.

Introduction

Research in the last decades has shown that digital technology like function plotters or computer algebra systems can facilitate the learning of mathematics in many different ways (Drijvers et al., 2016). For this reason, there is an ubiquitous call for the integration of these technologies into mathematics teaching. However current use of technology in the mathematics classroom still remains low:

“Nowadays there exist countless ideas, classroom suggestions, lesson plans and research reports for the use of new technologies in mathematics classrooms. But the situation concerning the real use of DT [digital technology] in mathematics classrooms has not succeeded in the way many had expected in the last decades.” (Weigand, 2014, p. 5; see also Heid, Thomas, & Zbiek, 2013, p. 599)

This indicates that the implementation of technology into the mathematics classroom is not a straightforward task and draws attention to the need to understand the factors influencing technology uptake. This is particularly important for the design of professional development (PD) programs which aim at supporting teachers’ when integrating digital technology. Research shows that beliefs and knowledge as well as external factors like school culture and resources play an important role (Heid, Thomas, & Zbiek, 2013, p. 630). However, less attention has been given to self-efficacy beliefs which capture a persons’ perceived ability to organize and execute courses of action (Bandura, 1997, p. 3). Therefore, this paper explores to what extend self-efficacy beliefs in the domain of teaching mathematics with technology influence the uptake of technology.

Theoretical background

Digital technology in the mathematics classroom comprises a plethora of different technologies. These range from general technology that can be used across different subjects (e.g. word

processing software like MS-Word) to subject-specific technology like digital learning environments, function plotters, geometry packages and computer algebra systems (CAS) that are specifically used in mathematics education. In this paper, unless stated otherwise, the term “technology” is used to refer to these specific tools, that are also known under the term “Mathematics Analysis Software” (MAS; Pierce & Ball, 2009). In the last 30 years, a great number of research projects has shown that MAS can support student learning in many different ways. For example, these tools can facilitate constructivist teaching approaches like discovery learning by giving pupils the opportunity to explore mathematical links on their own. In addition, digital tools can enhance conceptual understanding of mathematics by providing easy access to multiple and linked representations (Drijvers et al., 2016). For this reason, the use of technology in the mathematics classrooms is advocated for by researchers as well as teachers.

Despite this call for a deep integration of technology into mathematics teaching there is a “widely perceived quantitative gap and qualitative gap between the reality of teachers’ use of ICT and the potential for ICT suggested by research and policy“ (Bretscher, 2014, p. 43). Reasons for this are multifaceted and many different factors have been proposed in the last decade which can affect the uptake of technology. These factors include external factors like time constraints and resources (Thomas & Palmer, 2014, p. 72; Heid, Thomas, & Zbiek, 2013, p. 630). However, research indicates that the most important factor is the teacher who is ultimately responsible for how and when technology is used: “Clearly, schools can go only so far to encourage ICT use; actual take-up depends largely on teachers’ personal feelings, skills and attitudes to IT in general” (Mumtaz, 2000, p. 337). Therefore, internal factors like teacher knowledge and teacher beliefs have become the focus of attention. For example, the concept of TPACK (Mishra & Koehler, 2006) acknowledges, that a special type of knowledge is needed by teachers to teach mathematics with technology. Also, pedagogical beliefs, for example about constructivist or traditional philosophies of teaching mathematics, and beliefs referring to the teaching and learning mathematics with technology have been studied, showing that these beliefs can play an important role.

However, it seems that research has given little attention to teacher self-efficacy-beliefs when teaching mathematics with technology. Self-efficacy beliefs are defined as “a judgement of one’s ability to organize and execute the courses of action required to produce given attainments“ (Bandura, 1997, p. 3). This means, self-efficacy beliefs don’t capture the actual ability of a person but rather describe how someone perceives it. Research about the integration of general technology like word processing or presentation software across different subjects has found that self-efficacy beliefs play a crucial role for the uptake of these technologies (Ertmer & Ottenbreit-Leftwich, 2010; Wang, Ertmer, & Newby, 2004). As Ertmer & Ottenbreit-Leftwich note: “Although knowledge of technology is necessary, it is not enough if teachers do not also feel confident¹ using that knowledge to facilitate student learning” (Ertmer & Ottenbreit-Leftwich, 2010, p. 261). Therefore, it is

¹ The term “confidence” is often used interchangeably with the terms “self-efficacy” or “self-efficacy beliefs”. However Bandura notes that „Confidence is a catchword in sports rather than a construct embedded in a theoretical system“ (Bandura, 1997, p. 382). Therefore, we will use the term “self-efficacy beliefs” throughout this paper.

particular surprising that self-efficacy beliefs have not been studied in much detail in the context of teaching with MAS. Apart from the works of Cavanagh & Mitchelmore (2003, p. 16), Doerr & Zangor (2000, p.159) and Hong & Thomas (2006) where the role of self-efficacy beliefs becomes apparent subliminally at some points, we could only identify the work of Thomas & Palmer (2014) explicitly taking self-efficacy beliefs into account. They show that 42% of the surveyed teachers do mention lack of self-efficacy as an obstacle preventing teachers to use calculators more in their teaching. In addition, teachers with higher self-efficacy beliefs showed a more positive attitude to technology and to the use of technology in the learning of mathematics. Hence, they include confidence as a key factor in their model for technology integration. In summary, there seems to be some indication that teacher self-efficacy beliefs play an important role for the integration of technology into the mathematics classroom, but empirical evidence that teachers' self-efficacy beliefs about teaching with MAS is indeed linked to the classroom usage of technology is lacking.

Research question & methodology

The study aims to explore the link between self-efficacy and use of MAS. To achieve this goal, it is necessary to measure teachers' self-efficacy beliefs as well as teachers' technology use. Since the frequency of technology use can be more validly be self-reported by teachers compared to the quality of their teaching (Mayer, 1999) we focus on self-reported frequency of technology use and addresses the following questions: Do teachers with higher self-efficacy beliefs use MAS more often than teachers with lower self-efficacy beliefs? Which areas of technology use show particular strong links to self-efficacy beliefs?

To capture the frequency of technology use we used a likert-scale questionnaire (Thurm, 2018) assessing the use of technology in the following areas: (f1) use of technology for discovery learning, (f2) use of technology for linking multiple representations, (f3) use of technology when practicing, (f4) use of technology to support individual learning. In addition, a category capturing how often the use of technology was subject to critical reflection was included. Items in this category asked for example how often limitations of technology were discussed or how often there was a critical reflection about when to use pen & paper skills and when to use technology to solve a given task.

To measure teachers' self-efficacy beliefs, we developed a questionnaire that assessed self-efficacy in two domains (see below). For each of these domains a set of items was generated and refined until validity of the items was agreed on by teachers and experts. Response category was chosen according to Banduras "Guide for constructing self-efficacy scales" (Bandura, 1997) which recommends that teachers rate the strength of their belief in their ability on a scale from 0-100. In the following we give a brief description of each domain:

(s1) Self-efficacy related to task design & task selection when teaching with technology (4 Items)

The design of tasks is one of the most important factors when teaching with technology: „The inclusion of technology requires an understanding of the kinds of tasks that may utilize the resources provided by the technology to support students' high-level thinking“ (Sherman, 2014, p. 225; see also Drijvers, 2015). If teachers don't feel able to select and design appropriate tasks they are most likely to use their old tasks that are usually not tuned to the use of technology. Two sample

items of the scale were: I can design task for the use with MAS. I can distinguish between good and bad tasks for the use with MAS.

(s2) Self- efficacy related to lesson design & lesson implementation (4 Items)

These tasks however will not unfold their potential on their own. They need to be embedded in carefully designed lessons. Hence teachers must feel able to design and carry out appropriate lessons:

“[...] the teacher has to orchestrate learning, for example by synthesizing the results of technology-rich activities, highlighting fruitful tool techniques, and relating the experiences within the technological environment to paper-and-pencil skills or to other mathematic activities.” (Drijvers, 2015, p.148)

Two sample items of the scale were: I can design and implement lessons that support discovery learning using MAS. I am able to design lessons that make versatile use of MAS.

Both scales were administered in 2014 to 198 upper secondary school teachers within a larger research study (Thurm, Klinger, & Barzel, 2015) in North Rhine-Westphalia, Germany. In this state the use of MAS is compulsory in the final examination in upper secondary since the schoolyear 2014/2015. The average age of the teachers was 43 years, which is comparable to the average age of 45 years for all teachers in North Rhine-Westphalia. Teaching experience with mathematics was distributed as follows: 0-5 years (27%), 6-11 years (19%), 12-17 (16 %), 18-23 (11%), more than 23 years (25%). Due to the fact that MAS had been made compulsory only shortly before the study took place, there was a large number of teachers without any previous experience in teaching with MAS. In total, 52% had no previous experience teaching mathematics with technology and only 12% had more than 5 years' experience in teaching mathematics with technology.

Results

In a first step we used a confirmatory factor analysis to scrutinize the quality of the questionnaires on an empirical base. The goodness of fit was judged using the chi-square-fit index, the root mean square error of approximation (RMSEA), the standardized root mean square residual (SRMR) and the comparative fit index (CFI). The result for the self-efficacy questionnaire showed a good model fit with RMSEA = 0.041 SRMR = 0.022, CFI = 0.994, and $\chi^2 / df = 1.327$. The scales (s1) and (s2) also showed a good reliability with Cronbach' s alpha equal to 0.92 and 0.9 respectively. The goodness of fit and the reliability of the questionnaire assessing frequency of technology use were also high (see Thurm, 2018).

In first step we checked to what extend experience in teaching mathematics and teaching with MAS correlated with self-efficacy and frequency of technology use. As can be seen (Table 1) there is a small correlation between self-efficacy and the number of years teachers previously used technology in their classroom. Subsequently, we calculated the correlation between all scales on a latent level (Table 1). It is obvious that there are significant correlations between all subscales indicating that higher self-efficacy beliefs correspond to more frequent use of technology. Self-efficacy in the area of task design (s1) is most strongly linked to discovery learning (f1) and practice (f3), self-efficacy in the area of lesson design and implementation (s2) is most strongly

linked to discovery learning (f1) and individual learning (f4). In addition, it is remarkably that the scale (s2) consistently shows higher association with frequency of technology use than the scale (s1). Lowest correlation between self-efficacy and frequency of technology use is observed for the areas of multiple representation (f2) and reflection (f5).

		Self-efficacy			
Frequency of use		(s1) Designing tasks	(s2) Designing & implementing lessons	TE mathematics (years)	TE technology (years)
	(f1) Discovery learning	0.427***	0.564***	-0.03	0.14
	(f2) Multiple representations	0.230*	0.317**	0.06	0.07
	(f3) Practice	0.435***	0.445***	0.13	0.13
	(f4) Individual learning	0.391***	0.516***	-0.06	0.11
	(f5) Reflection	0.289**	0.293**	-0.15	0.03
	TE mathematics (years)	-0.08	-0.12	1	0.13
	TE technology (years)	0.27**	0.33**	0.13	1

Table 1: Result of the correlation analysis (* p<0.1, ** p<0.01, * p<0.001, TE=Teaching experience)**

Discussion

The study aimed to provide empirical evidence for the link between self-efficacy and using MAS. The results clearly indicate a strong relationship showing that higher self-efficacy beliefs are associated with more frequent use of technology. In addition, self-efficacy correlates only to a limited extent with teaching experience with technology, which indicates that teachers need additional support for developing their self-efficacy beliefs. In total, the results support the model of Thomas & Palmer (2014) who include self-efficacy as a key variable in their model of technology integration. Furthermore, the importance of self-efficacy becomes even more pronounced when noticing that the size of the correlation between self-efficacy and frequency of technology use is higher compared to the correlation of technology-related beliefs and frequency of technology use found in Thurm (2018). This indicates that self-efficacy beliefs might be even more influential for technology uptake than beliefs about the value of technology in the learning of mathematics.

But why do self-efficacy beliefs seem to play such an important role? One explanation might be, that teaching with technology poses a plethora of new challenges because it requires many changes in the teaching routines and attitudes. For example, traditional task that requires routine pen & paper skills easily become obsolete in the presence of a CAS. In addition, teaching with MAS can lead to more individualized learning, with greater uncertainty for the teacher who cannot longer simply follow a strict teaching plan. For example, Dunham & Dick (1994, p. 443) stress, that teachers teaching with technology need to be much more used to deal with unplanned situations,

show more flexibility and may experience a perceived loss of control. Especially for teachers that are used to a traditional style of teaching this can pose a major challenge:

“[...] the use of technology often means more individualized, student-centered classrooms in which teachers are no longer the sole source and authority of knowledge. This could be very disturbing to many teachers who are used to lecturing and other teacher-centered approaches because it requires them to abandon their routines and learn new ways of teaching.” (Zhao & Cziko, 2001, S.18)

From the results several recommendations for teacher education and professional development can be inferred. Firstly, programs must place a stronger focus on developing teacher's self-efficacy beliefs. Currently, knowledge, pedagogical beliefs and beliefs regarding the teaching of learning with technology seem to be the focus of most technology related professional development programs (e.g. Chamblee et al. 2008). Even though these factors might also increase self-efficacy, the most effective way of increasing self-efficacy is to enable successful mastery experiences for teachers. For example, Tschannen-Moran & McMaster (2009) compared different approaches for fostering self-efficacy beliefs in PD-programs and concluded that authentic mastery experience embedded in the teachers regular teaching context was the most powerful way to foster self-efficacy beliefs. In particular, they stress the role of individual support for teachers: “Without coaching to assist teachers in the implementation of the new skill, a significant proportion of teachers were left feeling more inadequate than they had before“ (Tschannen-Moran & McMaster, 2009, p. 241). However, programs that individually assist teachers to put theory into practice in this way appear to be quite rare in the context of teaching with technology (Grugeon et al., 2009, p.343). This might be due to the fact that individual coaching is quite resource intensive and hard to scale up.

For this reason, it might be fruitful to develop strategies for increasing self-efficacy even when individual coaching is not possible due to a lack of resources. For example, teachers might prepare a class for their fellow PD-participants and carry out part of the class during the PD-meetings. With this respect, approaches like micro-teaching or approximations-of practice (Grossmann, Hammermess & McDonald, 2009) could be a fruitful approach. Another way to increase self-efficacy could be the use of vicarious experiences which refers to hearing about or observing other teacher's successful technology integration (Wang, Ertmer & Newby, 2004).

Finally, the results from this study also give some indication about content selection for PD-programs. The result that self-efficacy beliefs are stronger correlated with frequency of technology use for supporting discovery learning than with frequency of technology use to support multiple representation might reflect that discovery learning requires much stronger self-efficacy beliefs due to its complexity. In contrast, the use of multiple representations is perceived as less complex and less challenging. PD-programs could therefore choose the support of multiple representations as starting point for novice teachers and advance to discovery learning in later stages.

In summary, this study shows that teachers' self-efficacy beliefs are an important factor when teaching mathematics with technology. PD-programs must provide means to strengthen teacher's self-efficacy beliefs if we want to take teachers needs seriously and change the degree of technology integration. Otherwise the outcome of PD-programs might be limited to knowledgeable

teachers that are convinced about the benefits of technology, but lack the self-efficacy to put their knowledge and beliefs into practice. We should not miss the final step that might be self-efficacy beliefs.

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