PROCEEDINGS

OF THE

46th CONFERENCE

of the International Group for the

Psychology of Mathematics Education

Haifa, Israel | July 16 – 21, 2023

PME-46

MATHEMATICS EDUCATION FOR GLOBAL SUSTAINABILITY

Volume 4

Editors: Michal Ayalon, Boris Koichu, Roza Leikin, Laurie Rubel and Michal Tabach

TOWARDS A SPECIFICATION OF DIGITAL COMPETENCES FOR STEM TEACHERS IN AN EDUCATIONAL CONTEXT. ELICITING EXPERTS' VIEWS

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Despite an increasing number of available frameworks for (future) teachers' digital competences, it often remains unspecified what teachers should know and be able to do. Hence, deciding on the focus of courses is still challenging. We initiated a Delphi process with stakeholders from research, school administration and practice in a local educational context to identify digital competences central for STEM teachers. This report covers the first stage of the process, where competence expectations synthesized from different frameworks were subjected to relevance evaluations. The results indicate a high degree of consensus among the experts, and experts from various fields of expertise differ only in a few aspects. We discuss how the process may inform others challenged to decide on questions related to (future) teacher education.

INTRODUCTION

Across the world, national policy actions stress the importance of preparing (future) teachers for working in a digital world. Hence, digital competences are seen as an essential aspect of the professional competence of teachers that enable teachers to use digital technologies in and for teaching. For instance, they should be able to integrate digital technologies effectively into teaching processes and use them for lesson preparation or communication with parents.

Several international (and also national) frameworks conceptualize digital competences or describe their range, for instance, the TPACK model (Koehler & Mishra, 2009) and the DigCompEdu (Redecker, 2017). However, existing frameworks for digital competences for teachers are hardly suited to decide what should be first and foremost targeted in courses fostering digital competence for (future) teachers of specific subjects. So, in many educational contexts, educators need to know what might be considered relevant by others holding responsibilities in the same context. This contribution addresses the problem for STEM teachers for (upper) secondary level in a first step by investigating whether it is possible to elicit a consensus of different stakeholders from research, school administration, and practice within an educational context regarding what might be relevant digital competences for all teachers.

THEORETICAL BACKGROUND

Digital competences of teachers can be described as a set of knowledge, skills, and attitudes related to the use of digital technology in education (Ferrari, 2012), and, accordingly, frameworks describe them in different ways. For example, the TPACK framework by Koehler and Mishra (2009) portrays teachers' professional knowledge

2023. In M. Ayalon, B. Koichu, R. Leikin, L. Rubel & M. Tabach (Eds.). *Proceedings of the 46th Conference of the International Group for the Psychology of Mathematics Education* (Vol. 4, pp. 3-10). PME 46.

as an overlap of technological, pedagogical, and content knowledge. This model is compact yet rather abstract and focuses on critical areas of teachers' knowledge, four related to digital competences. Another widespread framework for teachers' digital competences is DigCompEdu (Redecker, 2017). It comprehensively lists 22 different abstract competences in six areas. For example, teachers are expected to be able to use digital resources for teaching by creating and modifying them (2.1) or for professional collaboration (1.2), but they are also expected to support the students' responsible use of technology (6.4). Every competence is further characterized by hierarchical proficiency expectations in eight levels. Although this comprehensive framework is less abstract than TPACK, it still describes competences in a general manner and comprises a wide variety of different expectations.

Typically, digital competence expectations are also documented by national policies. In the federal state of Germany, for instance, the standing conference of ministries of education (KMK, 2017) issued competence expectations built on the cited frameworks and other resources. For instance, they incorporate ideas of critical education, which are often referenced in general education and its sciences, but not in (European) mathematics education (Skovsmose, 1985). However, the national policy documents also have commonalities with the international frameworks, like being very abstract.

As overarching documents, all frameworks are also limited informative regarding the expectations for teachers of specific subjects, for example, mathematics. At the same time, study results indicate that the use of digital technology differs between subjects, for example, mathematics and natural sciences (Mullis et al., 2020), so expectations may also have to be differentiated according to the subjects taught.

Moreover, the frameworks often lack information regarding an important question for the purpose of teacher education and training: What might be considered a minimal set of competences relevant for all (future) teachers? It can be assumed that even experts would answer the question differently, as teacher education and training are fields of shared responsibilities and partially disconnected (scientific) discourses.

RESEARCH QUESTIONS

This contribution addresses the problem of a need for more specific learning expectations regarding digital competences for (future) teachers. As described, current models of teacher digital competences do not guide what might be particularly relevant for teachers. They are also less informative regarding specific subjects, despite there is evidence that the use of digital technology differs between subjects. Moreover, general education reportedly uses different frameworks than subject-specific educational research, but there is a lack of evidence on whether the views of experts from different fields differ. According to our interest, we focus on STEM subjects which are often referenced as being at the fore of using digital technology.

We aim to answer the following research questions:

RQ1) Is there a consensus regarding which digital competences are relevant for all mathematics and science teachers by experts within a certain local context?

RQ2) Do experts with different fields of expertise (e.g., in the subjects, in general education) have different views on the relevance of competences?

DESIGN OF THE STUDY AND METHODS

The study is part of a larger study implementing the Delphi method (Diamond et al., 2014), which can be described as a moderated collaborative problem-solving process. This report covers the preliminary results of the first round, where we investigated whether experts' views on digital competence statements reached a consensus. As there were already frameworks for digital competences referenced in our educational context, we decided to start with a set of statements based on an analysis and synthesis of the frameworks (see below) in a structured online questionnaire. In this contribution, we report on the procedure and the results of this online questionnaire.

We expected the online questionnaire to be suited to identify statements seen consensually as relevant and others as not. The results should be used in the future second Delphi round to further specify learning expectations according to the identified relevant competence statements in group discussions with the experts. This should finally allow deciding on the design of courses for (future) STEM teachers fostering digital competences considered relevant by stakeholders with shared responsibilities in teacher education and training in our educational context.

Design of the Instrument

To identify a set of statements to be used in our questionnaire, we started analyzing the structure of an online course called *digi4all* (Seegerer et al., 2021), designed to equip pre-service and in-service teachers with basic digital concepts. As Seegerer created this course in collaboration with other subject education scientists through a similar consensus process, we expected the course to be a good starting point, yet being coined from the perspective of the author, a computer science education expert. We further subjected the frameworks of TPACK, DigCompEdu, and the relevant national educational policies, including the local curriculum for the school subject of computer science (indicating the local expectations of general education outcomes related to digital competences) to a qualitative content analysis. We synthesized the expectations of the different sources into statements and grouped the statements according to categories. Therefore, we merged and expanded the categories of *digi4all*, and the process resulted in eight competence areas (Table 1). When writing the statements, we aimed at easy readability of the statements and provided examples in case of possible divergent understanding of terms.

We structured the statements in each competence area in two parts differentiating between knowledge and skills. So, the statements in the first part referred to topics that may be expected to be known, whereas the statements in the second part referred to actions that may be expected to be mastered. To illustrate this, we present one statement referring to knowledge (indicated by K in the label) and one to skills (S) for the competence areas CA1, CA3, and CA6: “Binary number system as the basis of ‘digital functioning’” (CA1Kbin); “Operating with binary digits, e.g., conversion of binary to decimal numbers, binary addition, subtraction” (CA1Sbin); “Fundamentals of statistics” (CA3Kstat); “Evaluate collected information and data and present it appropriately for the addressee” (CA3Sstat); CA6: “Psychological effects of social networks (e.g., cyberbullying)” (CA6Ksocnet); “Using video conferencing tools” (CA6Svidcon).

Label	Content [number of statements]	Label	Content [number of statements]
CA1	Fundamentals of the functionality and use of a computer [14]	CA5	Fundamentals of media culture and influence of media on daily life [6]
CA2	Fundamentals of the functionality and use of the internet [10]	CA6	Communicating through and collaborating with digital technologies [10]
CA3	Getting, saving and evaluating data and information [11]	CA7	Designing digital learning environments (in general) [8]
CA4	Understanding, using and evaluating algorithms [8]	CA8	Using and evaluating subject-specific digital tools [8]

Table 1: Overview of the eight competence areas (abbr. CA) with a short description of contents and the number of statements identified.

To elicit what the experts considered to be digital competences relevant for all mathematics and science teachers, we asked them to rate each of the statements. The experts could rate the statement as being relevant for all teachers or not. They could further indicate whether they considered a basic level or an advanced level of knowledge/skills as necessary, which was asked to inform later stages of the Delphi process. In addition, they could decide not to rate the statement if they feel to do so (“This is not something I can assess”).

For each CA, the experts could comment in free text fields if they had suggestions for competences that are needed by all teachers but not covered by the presented statements. It was possible for the experts to navigate freely through the questionnaire at any time and to change the given answers.

Sampling method and sample

The experts for this questionnaire were intentionally sampled. Our educational context refers to a German federal state (Thuringia) and the Gymnasium level. All future secondary teachers for this level are educated at one university. Since our focus is on mathematics and science, we contacted all STEM education professors. In addition, we also contacted professors in the field of educational sciences that are responsible for the general education parts of teacher education. Finally, we contacted the ministry of education of the federal state as representative of the educational administration. In each case, we contacted the head of the department. We asked for personal participation and the nomination of a given number of post-/doctoral researchers or employees with relevant expertise to participate in the questionnaire. In addition, we asked to nominate up to two expert teachers experienced in mentoring future teachers and one subject expert (professor) experienced in teaching future teachers for each subject. Overall, we aimed at a list of 5 to 7 participants per field of expertise. With this sampling strategy, we intended to mirror the shared responsibilities in teacher education and training in our educational context.

To investigate RQ2 regarding potential differences according to the experts' field of expertise, we build groups as follows: Mathematics and computer science (group 1), biology, physics, and chemistry (group 2), educational sciences and educational administration (group 3). Whereas group 2 refers to the natural sciences, group 1 spans computer science and mathematics as subjects with a common root and (still) partly common grounds in mathematics. Group 3 represents experts that have, by nature of their professional field, a general perspective on teachers and their competences independent of the subjects taught.

In the end, we invited 46 people to take part in our questionnaire as experts. We informed the experts about the goals and procedures and whether they were free to participate. The experts were informed that we could identify responses with personal information, which is necessary for the next round of the Delphi process. This research report is a working report by the time of January 2023. At this time, we received complete responses from 36 of the invited experts (age: M = 43.7; SD = 12.4).

Group	Field of expertise	Number of responses	Response rate
1 (n=14)	Mathematics (MA)	6	86%
	Computer Science (CS)	8	89%
2 (n=11)	Biology (BI)	4	80%
	Physics (PH)	4	80%
	Chemistry (CH)	3	60%
3 (n=11)	Educational Sciences (EdS)	6	60%
	Educational Administration (EdA)	5	100%
	Total	36	78%

Table 2: Number of participants by field of expertise and response rates.

Data analysis

We report the experts' rating of the full set of 75 competence statements structured in eight competences areas. We treated answers where experts decided not to rate the statement as missing. To answer RQ1, we counted whether experts considered each statement as a relevant requirement for all teachers without differentiating between possibly different levels of sophistication the experts might expect (basic vs. advanced) statements seen by at least 75% of the experts as being relevant were considered consensually representing a relevant expectation (typical Delphi criterion, Diamond et al., 2015). Some experts provided additional comments in the text fields provided with each competence area (98 written comments in total). The detailed analysis of these comments cannot be part of this working report, but a first inspection led to the impression that the responses were mainly comments on the presented statements with few suggestions for additions.

Regarding RQ2, we subjected differences in agreement rates between the groups of experts with different fields of expertise to a *Chi²*-test of independence and manually inspected observed differences.

RESULTS

General findings will first be reported aggregated for the competence areas. With our criterion of 75% necessary agreement rate, we note a trend over the different competence areas. As CA1 to CA4 are more about the technical and general aspects of using technology and five to eight are more about teaching-specific aspects, nearly all statements in the competence areas five to eight exceeded the 75% agreement criterion. For example, the statements CA6Ksocnet and CA6Svidcon (see above) reached 100% agreement rates. In contrast, several statements did not reach the specified agreement rate in CA1 to CA4. For example, the statement CA1Kbin reached 52%, and CA1Sbin only 13% agreement rate. However, overall relevance agreement rates were high (M = 80%, SD = 23% agreement rate). To answer RQ1, the experts' ratings indicate that 59 out of the 75 presented statements were consensually considered to be relevant for all (future) STEM teachers, at least on a basic level.

CA 1	CA 2	CA 3	CA 4	CA 5	CA 6	CA 7	CA8
10 of 14	5 of 10	9 of 11	3 of 8	6 of 6	10 of 10	8 of 8	8 of 8

Table 3: Number of statements with an agreement rate at or above 75% across all experts (N=36) in each competence area.

Regarding RQ2, we exemplarily focus in this report on CA1 and CA3, as the experts' responses show certain variations in these areas. The results of the *Chi²*-test indicate that only for 2 of the 25 statements, there are significant differences between the agreement rates. To illustrate how the experts' views differ in our study, we present details for selected statements. Among the statements in CA1, we presented two statements referring to skills in using software for text editing and presentation. The experts consensually rated these as relevant for all teachers (100% agreement rate).

	Overall	Group 1 MA + CS	Group 2 BI + CH +PH	Group 3 EdS + EdA	*Chi²*-test
CA1Kbin	52%	29%	44%	90%	*
CA1Sbin	13%	7%	11%	22%	n.s.
CA3Kstat	61%	67%	67%	50%	n.s.
CA3Sstat	100%	100%	100%	100%	n.s.

Table 4: Agreement rates split up by groups on selected statements of CA1 and CA3 to illustrate how experts' responses vary (* < .05, n.s. not significant).

In contrast, the two CA1 statements about binary numbers given above achieved varying agreement rates (Table 4), with the agreement of group 1 lower than group 2 and the agreement of group 2 lower than group 3. But, the descriptive differences correspond only for CA1Kbin to a significant difference. As other examples, in CA3, we presented two statements about statistics, one referring to knowledge (CA3Kstat) and one to skills (CA3Sstat). Despite certain variances in agreement rates between groups (Table 4), the differences cannot be considered statistically significant.

To sum up, and as already indicated by the high consensus rates reported above, the views of experts with different fields of expertise only differ in a few cases. It has to be noted that we exemplarily focused on CA1 and CA3 in this preliminary report, and the analyses of the other two areas showing certain variations are pending.

DISCUSSION

This contribution reports the results of a study investigating whether experts of different fields of expertise in an educational context have similar views on what is considered digital competences relevant for all STEM teachers. As a starting point, we presented a set of 75 statements in eight competence areas synthesized from different frameworks. The results indicate that the experts consensually rate a wide range of statements as relevant for all teachers. We see indications that the consensus is almost perfect when expectations are particularly teaching-specific, as in competence areas “fundamentals of media culture and influence of media on daily life” (CA5), “communicating through and collaborating with digital technologies” (CA6), “designing digital learning environments (in general)” (CA7) and “using and evaluating subject-specific digital tools” (CA8). For less teaching-specific areas, experts’ ratings are more differentiated so that, for example, general skills like using standard software for text editing are undisputedly seen as relevant. At the same time, questions related to the hidden principles of technologies, like binary numbers or statistical principles, did not reach a consensus in our study.

Against expectations, the results of our preliminary analysis suggest that differences between the groups of experts from different fields of expertise are not very salient. We illustrated this by the examples of the statements referring to the binary system and its operations. From a mathematical point of view, it is remarkable that the relevance agreement rates are generally low but lowest for the group of experts from mathematics and computer science and highest for the educational sciences and administration group, which seems paradoxical at first sight. One possible explanation might be that experts more familiar with these concepts underestimate their relevance. We will use the planned group discussion to elicit the reasonings behind the relevance ratings by experts from different fields for possible explanations.

Our study certainly has limitations. First, we must remember that we focus on a certain educational context. Hence, the findings are not generalizable across contexts. However, to our knowledge, studies that systematically investigate whether experts with shared responsibility in teacher education and training have similar or different views on digital competence expectations are rare. Our methods might also inform other studies addressing similar teacher education problems. Second, so far, our competence statements are still abstract and may be interpreted differently by experts with different backgrounds. In addition, we did not consider whether the experts' views might show considerable variability regarding the expected level of the competences, even if a statement was consensually rated as relevant. We will focus on these aspects in further analyses of the data and the second round of the Delphi process, where we intend to initiate group discussions and aim for a consensus on the level of specific expectations of mastery. The process might still show that, despite a perfect agreement regarding the competence statements (e.g., teachers have to know about the "Functioning of social networks", CA6Kfunsoc), experts with different backgrounds, like mathematics educators and general educators, may mean something different by this statement.

On the one hand, our findings underline the relevance of a wide variety of digital competences for (future) STEM teachers. On the other hand, our study shows that the original problem of deciding what should be covered by teacher education courses remains even though we applied a strong consensus criterion. This is remarkable, given teacher education and training experts' diverse backgrounds. However, it also suggests that the different stakeholders with shared responsibilities in teacher education and training might succeed in initiating a common discourse.

ACKNOWLEDGEMENTS

This study is part of THInKI, founded by the BMBF (Federal Ministry of Education and Research) with the registration number 16DHBKI084.

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