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Prompting teachers' reflection of their professional knowledge. A proof-of-concept study of the Graphic Assessment of TPACK Instrument

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ABSTRACT

Many educational technology proponents support the Technological Pedagogical Content Knowledge (TPACK) model as a way to conceptualize teaching with technology, but recent TPACK research shows a need for empirical studies regarding the development of this knowledge. This proof-of-concept study applies mixed-methods to investigate the meta-cognitive awareness produced by teachers who participate in the Graphic Assessment of TPACK Instrument (GATI). This process involves creating graphical representations (circles of differing sizes and the degree of their overlap) that represent what teachers understand to be their current and aspired TPACK. This study documented teachers' explanations during a think-aloud procedure as they created their GATI figures. The in-depth data from two German teachers who participated in the process captured the details of their experience and demonstrated the potential of the GATI to support teachers in reflecting about their professional knowledge and in determining their own professional development activities. These findings will be informative to future pilot studies involving the larger design of the GATI process, to better understand the role of teachers' meta-conceptual awareness, and to better ascertain how the GATI might be used to support professional development on a larger scale.

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The Technological Pedagogical Content Knowledge (TPACK) framework (Mishra and Koehler 2006) is very popular among educators who promote the use of technology for teaching and learning. The framework includes knowledge bases or competencies, each of equal importance, in developing expertise in the ability to integrate technology. The three main knowledge bases are knowledge of curriculum (CK), knowledge of pedagogy (PK), and knowledge of technology (TK). A Venn diagram (see Figure 1) is used as a way to represent the complexities of discrete yet interrelated knowledge types (TCK, TPK, and PCK). Ultimately, the use of a Venn diagram is an attempt to simplify the multiple aspects

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⁺Contributions of the authors to this article were equal. We rotate authorship in our writing.

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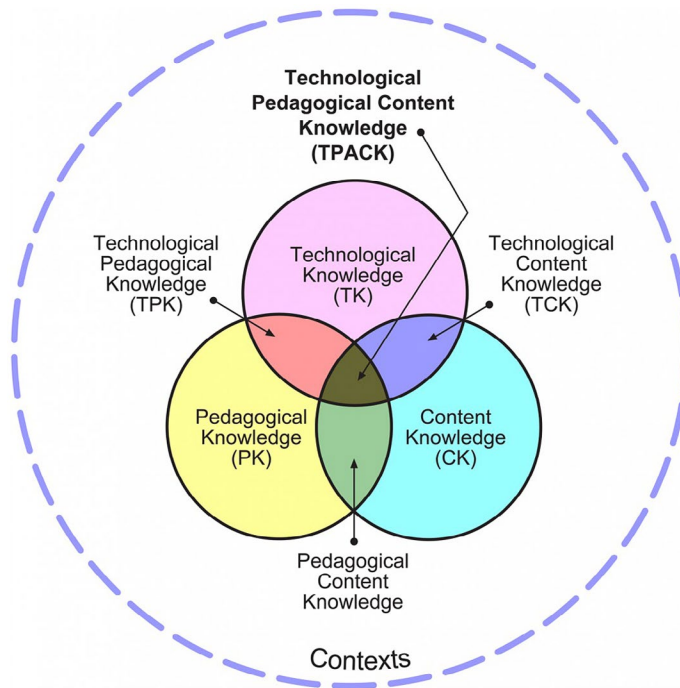


Figure 1. TPACK Venn diagram represents interactions among the three knowledge bases that are thought to be important for teachers who integrate technology.

of a teacher's professional knowledge that come into play when teaching with technology in *their* classroom (context). TPACK then, accounts for the many factors involved with becoming expert in teaching with technology. (For a current review of the literature see Voogt et al. 2012.)

Due to the importance of context in the TPACK framework, applying TPACK to teaching scenarios where technology is integrated can add richness to the conversation about what it means to teach with technology. Conversations about context can create a more complex picture by pointing out the multifaceted, interrelated, and situated nature of the knowledge required by teachers who want to teach with technology. With this understanding in mind, authors of this study wanted to develop a practical application of TPACK as a framework that capitalized on contextual understandings only teachers hold, and might support teachers in professional development surrounding teaching with technology.

The Graphical Assessment of TPACK Instrument (GATI) is a process designed by the researchers to help teachers map their professional knowledge and prompt self-reflection through meta-conceptual awareness. This study was designed as a proof-of-concept exploration in order to ascertain the feasibility of the GATI, to inform future pilot studies, and to specifically verify use of the tool as a professional development process. A mixed-method approach was used to demonstrate the potential of the GATI to heighten teachers' ability to reflect about their classrooms and teaching practice, and about ways to improve their ability to integrate technology.

Literature review

TPACK as meta-conceptual awareness

Educational technology scholars have started to acknowledge that, given the complexity of learning to teach with technology, integrating meta-cognitive aspects into the framework might be helpful (Kohen and Kramarski 2012; Kramarski and Michalsky 2010; Krauskopf, Zahn, and Hesse 2015; Michalsky and Kramarski 2015). Reviewing TPACK from a meta-cognitive perspective provides opportunity to conceptualize the framework as a coherent theory. This means developing TPACK in teachers would correspond with developing an understanding of what one knows and what one needs to know in order to effectively teach with technology (Krauskopf, Zahn, and Hesse 2015).

This line of thinking extends upon Shulman's (1986, 1987) work by introducing the notion of *meta-conceptual awareness*, the meta-cognitive ability to reflect on professional competence and positively influence the development of teaching skills. In the case of TPACK, meta-conceptual refers to what a teacher knows about her or his own knowledge in the three TPACK domains, and their strategies to intertwine these for planning and implementing lessons by adding technology or by purposefully refraining from using technology in a given context. Following Shulman's notion, we are interconnecting TPACK and meta-conceptual awareness. This, in turn, means that developing TPACK is defined as teachers actively constructing their understanding within the proposed domains and taking into account any learning goals that arise through the process. Following this line of thinking, teachers with this level of insight related to their professional development needs might be able to customize their professional development related to technology integration, and especially account for their unique context. In other words, teachers who utilize the GATI would likely take more ownership of their craft and their personal professional development needs.

Furthermore, to successfully master a multifaceted concern such as teaching with technology, teachers need to understand the teaching task itself as another source of varying constraints (Koehler and Mishra 2008), an aspect Berliner (1992) described as the *sensitivity* to the demands of the teaching task and the situation. Given this variation, teachers are always afforded – at least implicitly – the option to monitor their current professional knowledge to determine whether they have met or will be able to meet certain teaching challenges. This argument points to educational theories of self-regulated learning, which consider cognitive and motivational, as well as meta-cognitive processes, as necessary components for (teachers) students to attain their (professional) goals in a given environment (cf. Zimmerman 2000). From a meta-perspective, it would be necessary for teachers to determine their available (cognitive) resources and strategies for reaching the desired goal state, namely creating solutions to design and enact concrete learning opportunities. In sum, TPACK as meta-conceptual awareness would then refer to the level of organization of teachers' professional knowledge necessary for creating learning environments (cf. also Koehler and Mishra 2008; Leinhardt and Greeno 1991), but not so much to a body of knowledge that is circumscribable and fixed.

There are two lines of research found in current literature that support the notion of TPACK being a meta-conceptual awareness. First, the TPACK-Self-Regulated Learning model, developed by Kramarski and colleagues, promotes self-regulated learning as an effective way of supporting (pre-service) teachers' TPACK development (Kramarski and Michalsky 2010; Michalsky and Kramarski 2015). This work supports notions of meta-conceptual awareness because in order to self-regulate one's learning it is necessary to become self-aware of one's existing known and

unknown knowledge as well as the task at hand and the context of its performance. Specifically, in their empirical work, these authors demonstrated that, in comparison to control groups, prompting teachers to reflect on the added-value components of technology in a given teaching scenario improved participants' performance in lesson planning.

A second approach suggests developing TPACK is strongly connected to constructing complex mental models of how to combine the different sub-domains in order to create technology-supported learning environments. In other words, teachers who master TPACK and also reflect on their TPC knowledge will better translate professional knowledge into learning experiences for students that make good use of technology (Angeli and Valanides 2009; Cox and Graham 2009; Foulger, Krauskopf, and Williams 2012). Moreover, the argument of Krauskopf and colleagues (Krauskopf, Zahn, and Hesse 2012, 2015; Krauskopf et al. 2014), that TPACK can be developed by constructing mental models of the affordances of technology in learning contexts, provides a scaffold for reflective processes in teachers. Mental models are characterized as *analogous* mental representations of elements and their interrelations, which cannot fully be captured by verbal means. Mapped onto the context of TPACK, teachers construct models that involve elements of context such as themselves, students, their classrooms, tasks, learning goals, etc., and demonstrate how these various elements influence one another during learning situations. Mapping TPC knowledge in this sense requires a combination of verbal *and* other modalities, as well as meta-cognitive activities (cf. Johnson-Laird 1983; Vosniadou 1994). Applying this line of thinking, for the development of TPACK and applications of technology integration in teaching and learning contexts, teachers adapt mental models by mutually considering professional teaching practice and theory-based reflection (Cochran-Smith and Lytle 1999; Zeichner 1994), in other words self-regulated learning.

In sum, TPACK as a professional knowledge structure signifies that teachers need to understand and know many things, *and simultaneously* reflect on their knowledge and understanding in order to develop professionally. Thus, the professional development path to TPACK is neither fully developmental, nor fully based on experiences such as 'training' (Koehler et al. 2014). Rather it is most likely based on a complex interaction between teaching experience and training, and therefore needs support for guided self-reflection as prerequisites for teachers' self-regulated learning.

Introducing the GATI

The authors of this study desire to provide teachers with a tool and process that would help teachers gain an understanding of their knowledge and skills for teaching with technology, and support their professional development by providing authentic and autonomous methods. Armed with the assumptions about how meta-conceptual awareness might support teachers' professional development, the GATI was created. The GATI process utilizes visualization and reflection activities for teachers to increase their meta-conceptual awareness. The process allows for external observers, such as professional developers, to provide guidance to the process as well as to gain insight about how to support the teacher in their TPACK development. To our knowledge, this is a unique way of viewing the development of TPACK in educators, and no other process has been used or documented that applies a similar line of thinking.

Teachers who participate in the GATI process are first given a template with a set of six circles of graduated sizes for each of the three knowledge areas of TPACK (see Appendix 1), and are asked to indicate their current professional knowledge in each of the three domains,

relative to one another. Next, teachers are asked to physically manipulate their circles to demonstrate the amount of inclusion, exclusion, or intersection between their three knowledge domains. The resulting Venn diagram represents knowledge bases that differ as well as representative ‘amounts’ of overlapping knowledge.

Once their Venn diagram is created, teachers are asked to explain how they decided the size of each circle and the amount of overlap (if any) among the three circles; any areas showing ambiguity are probed to strengthen the teacher’s clarity. Then teachers create a second Venn diagram to represent the professional knowledge for which they are striving, and again provide explanation. At this point, goals or activities for professional development might be established. See Figures 2 and 3 for example images of current and future diagrams.

Method

The practical goal of this study was to conduct a proof-of-concept investigation of what the authors feel might be a helpful tool when used as a scaffold for teachers’ professional learning as related to integrating technology. A proof-of-concept study is a demonstration of the feasibility that certain concepts or theories have the potential for larger application. It is not a pilot study; it is designed to determine the likelihood of feasibility of a concept before a pilot study is conducted and generally has a very small sample size (Campbell 2013; Core Fundamentals in any Proof of Concept 2014; Larusson 2015; Mishra 2015).

This study was initiated as a proof of concept for the GATI process in order to determine the feasibility of the process to be used as a professional development tool, and to later inform a series of pilot studies with wider applications and more participants. Proof of concept is used in various fields (e.g. software development, engineering, lab sciences, and business). While a proof of concept implements various specific characteristics, it includes the general process of (1) defining, (2) engineering a solution, (3) testing with a small sample, (4) evaluating

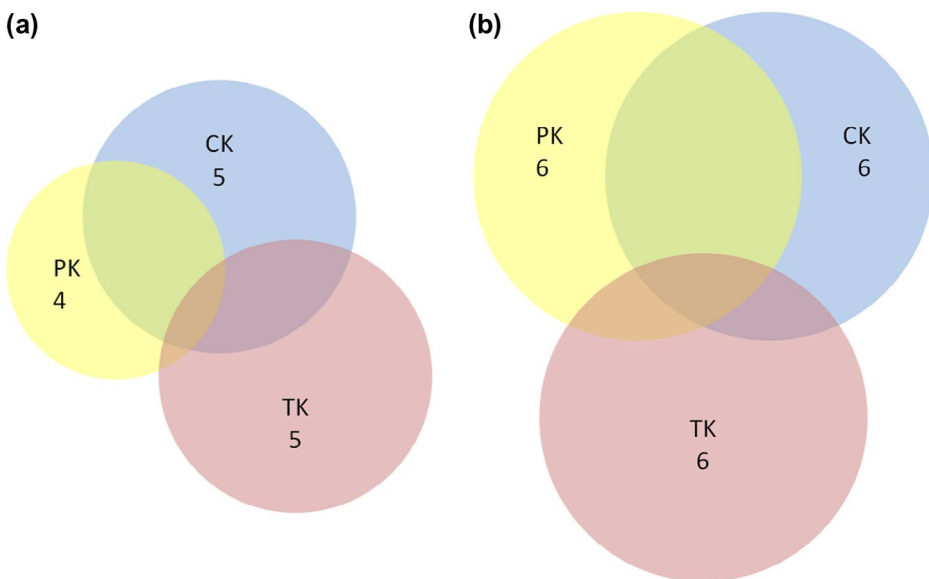


Figure 2. Heinz’s GATI of his (a) current and (b) next aspired state knowledge structure.

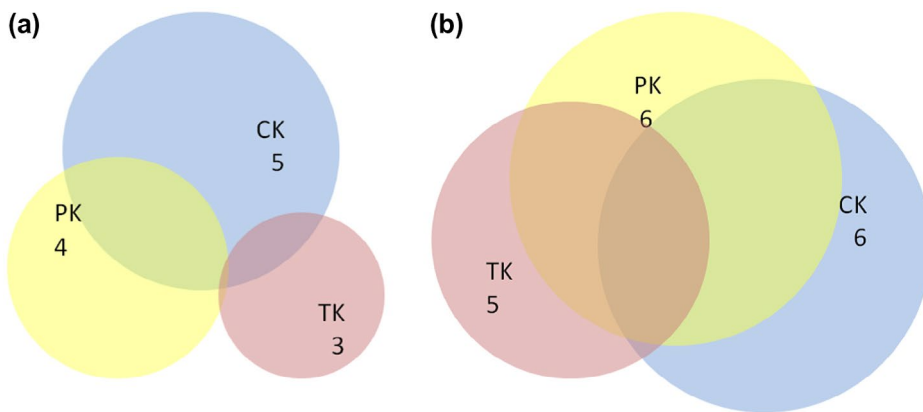


Figure 3. Marianne's GATI of her (a) current and (b) next aspired state knowledge structure.

based on defined goal, (5) making a decision about if and how to move forward (Blanchard and Fabrycky 1998; Budynas and Nisbett 2008; DeGrace and Stahl 1990; Mishra 2015). It is viewed as an opportunity to demonstrate capabilities, in a small and controlled manner, and to inform the investment in future development. According to the Framework Guidelines for the Proof of Concept Metric, a document created by the Science Industry Australia (Science Industry Australia, Proof of Concept Advisory Group 2006, 2), a proof of concept is a hands-on experience that 'demonstrates the attractiveness of taking an innovative idea into ... development.' With the goal of informing usable innovations, rich data are encouraged.

Conceived as a proof of concept, the study was guided by two overarching points of inquiry:

Q1: What understandings of TPACK domains and sub-domains will teachers gain when creating and explaining their GATI?

Q2: What insights about teacher learning can be obtained from completing the GATI process with teachers, and how might this inform a teacher's development of TPACK?

Participants

Researchers sought rich understanding from the experiences of a limited number of teachers' individual experiences with the GATI process, and because the present study followed a proof-of-concept design, only two participants were chosen. The lead author specifically chose Heinz and Marianne because they were both interested in professional development and were already familiar with technology use in their private lives. Additionally, they had a common background in their preparation, being trained in the same federal state (Bundesland) of Germany. Although educational technology courses may be included unsystematically in teacher preparation in Germany, the TPACK framework is not part of teacher training, and neither Heinz nor Marianne was familiar with the framework. Neither participant had a specific technology focus in their professional responsibilities at school.

The demographics reported in the questionnaire (see Table 1) were used to write the following descriptions. Additional information known by the researcher about the local context is included for the benefit of helping international readers more fully understand the teaching situations. For the quantitative component of the study, participants rated their

perceived knowledge in all sub-domains of the TPACK framework on a German translation of the questionnaire developed by Schmidt et al. (2009) (see Table 2).

Heinz was in his mid thirties and had been working as a teacher for seven years. His first 1.5 years included the Referendariat, which is a praxis phase of teacher training in Germany where new in-service teachers attend classes on general and subject-specific pedagogy. Whereas most German teachers are qualified to teach two subjects, Heinz is qualified to teach three: mathematics, biology, and Italian. During the time of the study, he was teaching mathematics and the natural sciences. In the past, he taught almost all grade levels of the German Gymnasium (5–13), which is the high school track students need to attend if they want to study at a university. He was teaching a wide range of grades during this study. Heinz indicated he anticipates a promotion to be a professional developer in his district. Regarding the technology at his current school, he reported access was not good enough. He had privately bought an iPad to use for teaching and organizing his own materials with Endnote. During the GATI process, he reported feeling comfortable with the protocol. Accordingly, he provided much detail without the need for many prompts and did not seem to have problems with verbalizing his thoughts during the completion of the visual task.

Marianne was also in her late thirties and had been working as a teacher for eight years including Referendariat. She has a background in humanities and is qualified to teach three subjects: German, French, and Italian. At the time of this study she was teaching German and French. In the past she taught all grade levels of the German Gymnasium, but during the time of the study was teaching classes at a reduced range because she had recently returned from maternity leave. Marianne claimed her current school is less equipped with technology such as student laptops/computers than she would like. She specifically mentioned interactive whiteboards as an available technology. In contrast to Heinz, she did not report having personally invested in specific technology to assist in her teaching. During the GATI process she seemed less confident, and mentioned that videotaping made her uncomfortable. Overall, her verbalizations were shorter and more prompts by the researcher were required for her to fully address the questions.

Innovation and mixed-method measures

Heinz and Marianne participated in the three-part process separately to build their current and aspired GATI model and to reflect about their thinking when creating their GATI diagram

Table 1. Overview of demographic and survey information for the two cases.

	Heinz	Marianne
Age	34	36
Teaching experience	7	8
Subjects taught	Mathematics, Biology, Science	German, French
Grades taught at present	5, 6, 8, 9, 11, 13	6, 9, 11
Technology access at school	Computer lab, teacher computer, mobile laptops (ratio 1:2), LAN in classroom, other technology: graphic calculators, digital cameras, projector, TV, DVD	Computer lab, teacher computer, classroom computers in some rooms (ratio 1:5+), other technology: interactive whiteboard, graphic calculators, digital cameras, projector, TV, DVD
Conception of knowledge and skills for teaching with technology	Practicing at home, readiness of mind, Windows, Office, know how to play back media; time to familiarize, interest, and [suitable] basic beliefs	Common sense, basic technological knowledge, basic PC skills

Table 2. The means of self-rated knowledge in the TPACK domains based on scale adapted from Schmidt et al. (2009) for the two cases.

	Heinz	Marianne
TK	4.3	3.2
CK	4.7	5.0
PK	4.1	4.6
PCK	4.0	5.0
TCK	5.0	5.0
TPK	3.8	4.4
TPACK	4.8	3.8

Note: Values representing the upper limit of the scale are displayed in bold.

as well as their ideas about professional development activities that would help them attain their next aspired state. During the process, conducted by the lead researcher, the teachers were asked to think out loud. The detailed data, characteristic of a proof-of-concept study, allowed the researchers to review two unique experiences with great detail, so that understanding of the many facets of each individual teacher's experience could be documented. Both participants provided their written informed consent.

First, each teacher completed a questionnaire that collected demographic information, information about their teaching, and the technological equipment available at their school. The questionnaire also included a self-report assessment of their TPACK and all its sub-domains using a five-point Likert scale (Krauskopf, Williams, and Foulger 2013; adapted from Schmidt et al. 2009). These items were rated on a six-point Likert scale. The survey was administered in German for comprehension ease of the teachers, whose first language is German.

Next, participants were asked to create their own GATI model using a template containing six sets of circles of graduated sizes representing technological (TK), pedagogical (PK), and content (CK) knowledge (see Appendix 1). They were provided with basic definitions of these three knowledge bases. The six circles for each domain ranged in diameter from 1 to 6 cm, the smallest circle representing novice-level knowledge and the largest representing expert-level knowledge. Participants were asked to select the circle for each domain that best represented their current knowledge base at that time, relative to one another, then to position them based on how they viewed the interrelatedness (inclusion, exclusion, or intersection) of their knowledge bases. After this, they were asked to explain how they made their decisions; probing questions were asked in order to help participants elaborate on contextual information that was relevant to their decisions. Each teacher was then asked to complete another GATI model to represent the professional knowledge for which they were striving, as what they considered to be the most logical next step (see Appendices 2 and 3).

The third phase of the process involved teachers explaining to the researcher how they might progress from the current status to their next aspired state. During this conversation they were asked to identify supports, tasks, and/or materials that would help them attain their next aspired state.

The entire process was videotaped. Video data were analyzed for the participants' perceptions of each TPACK domain as they represented it regarding the dimensions of circle size and overlap. The step-by-step approach for qualitative analysis, as described by Auerbach and Silverstein (2003), was used to identify emerging themes within participants' descriptions of their subjective theories about professional development. Data analyzed included the GATI models of the participants' current and next aspired state, audio recordings of the

think-aloud conversation facilitated by the researcher while participants created their models, as well as audio recordings of conversations with the lead researcher about the meaning of the different areas of their GATI diagram and how they saw themselves advancing from their current state to their next aspired state.

Results

Results are presented according to the two overarching points of inquiry of this study. Responses of both participants are presented together, as a way to demonstrate participants' unique reactions to the GATI procedure. A focused response to the two research questions lies on the assumptions the two participants explicate regarding their professional learning as a result of participating in the GATI as a professional development method. When presenting quotes, the audio recording time stamp is noted after each quote.

Q1: What understandings of TPACK domains and sub-domains will teachers gain when creating and explaining their GATI?

TK. Heinz was very confident about his technological knowledge, stating that his TK 'is pretty sound' (HEINZ.00:00:51-1). Heinz chose the 5-cm circle. With regard to his understanding of this construct, he discussed it either in relation to his subject (TCK) or to general pedagogy (TPK). Due to his subject's close connection to technology, his understanding of TK also seemed to merge with content knowledge. In spite of this, he clearly distinguished technological skills from this as he stated:

Thinking about biology and technological knowledge that almost doesn't overlap at all; only maybe in bioinformatics. With regard to contents... Practically, which laptop do I use, how do I turn on a projector, that on the other hand is a different kind of knowledge. (HEINZ.00:02:20-3)

In contrast, Marianne chose the 3-cm circle and described TK as being more discrete from PK and CK. This was evident in her depiction of her next aspired professional knowledge structure when she stated, 'Well that [TK] is for me always a little farther apart, because I do consider it as an auxiliary means and not as a basic competence' (MARIANNE.00:07:17-4). Additionally, Marianne specifically referred to emerging new technologies as the focus of TK. When asked what she considers important to know, it was clear that to a certain extent she conceptualizes TK as technological skills. Thus, TK for her is mostly a prerequisite to make things work in class; however, depending on how much working technology is needed for a specific teaching experience, the TK circle only peripherally touched the other two. Marianne explained this by saying,

in this case it doesn't matter whether I have [TK] or not. Then it would look more like this, [with the circles] merely touching. But if it was somehow essential that I know my stuff, then I would need to push it farther in [to the other circles]. (MARIANNE.2.00:06:03-8)

CK. Both Marianne and Heinz considered knowledge of their subjects as a key feature in their GATI model, and chose the 5-cm circle to represent this knowledge. Heinz indicated that modesty might be a reason for not choosing the biggest circle. He added, 'You can always know more' (HEINZ.00:00:51-1). Marianne explained that for her the CK sub-domain is well circumscribed and a somewhat stable construct. In her words, 'Actually, I somehow am an expert on the topic of knowledge, am I not?' (MARIANNE.00:01:39-0) and 'Instead,

content knowledge is actually pretty simple. I think it is clear like this, as a circle' (MARIANNE.2.00:04:43-7).

PK. Heinz described PK as the essence of the teacher profession, whereas Marianne made no such inference. Both chose the 4-cm circle to represent their current pedagogical knowledge and were specific about positioning the circles in such a way that a considerable part of PK did not overlap with any of the other two. Both teachers justified this decision with the argument that there are many professionally relevant situations other than teaching in the classroom, such as students' personal problems, or communication with colleagues or the principal. The following quotes exemplify this finding:

Pedagogical knowledge you can expect from a teacher 100%. That's his profession. (HEINZ.00:04:27-7)

Pedagogical knowledge needs to also cover a large area outside of content knowledge. Because if you deal with students' problems and other problems ... If I pushed that into the content knowledge only [PCK] (German: *Fachdidaktik*) would remain. ... That is why I want at least half of the pedagogical knowledge outside of [the CK circle]. (HEINZ.00:04:27-7)

When I think about pedagogical knowledge I also think about talking to colleagues and the principal. That does not necessarily concern teaching in the classroom. (MARIANNE.00:09:23-8)

PCK. In general, both participants saw the overlapping circles as representing something positive, and thus devised relatively large overlapping areas for their GATI models for both their current and next aspired state (see Figures 2 and 3). However, as mentioned above, both were aware that any overlap needs to be considered with care, because they consider knowledge in the basic sub-domains also as professionally relevant. When discussing PCK and the other two overlapping sub-domains, Heinz and Marianne both associated a qualitative change that is represented by the overlap (see also PK). However, only Heinz specifically addressed PCK (*Fachdidaktik*). The following quotes exemplify this finding:

If I let the [PK and CK circle] overlap like this, it means that they are interacting. So I can somehow use [this knowledge] in an interacting way and it mutually influences each other and that is somehow a positive effect. So, the more overlap the better it is for my teaching. (MARIANNE.00:03:48-7)

I will simply assume that PCK [Fachdidaktik] is represented exactly by the overlap [of PK and CK] and this should be pretty large. (HEINZ.00:02:20-3)

Regarding the visual representation, Heinz described his doubts and his reasoning before he decided to define the overlapping area of PK and CK as PCK as he noted, 'But what I want for and what I am concerned with now, is actually the PCK [Fachdidaktik]. Because ... I don't know whether to put it into the content or the pedagogical knowledge' (HEINZ.00:02:20-3).

TCK. Regarding the interaction of technological knowledge and content knowledge, there was a noticeable difference between the descriptions of Heinz and Marianne based on their different subjects. For Heinz there was a strong connection to his science teaching, although for biology he saw less connection. However, he was ambiguous regarding TCK when referring to technology as part of the subject matter. He explains this through several quotes:

Now I have to create a connection between the circles. Well, that depends very much on the subjects, but my subjects are related to technology. Yes, for Science & Technology that connection is very, very tight. (HEINZ.00:02:20-3)

And now I would say, because I teach a technology-related subject, there is a large overlapping area. At least a quarter. (HEINZ.00:02:20-3)

In contrast to Heinz, Marianne was less ambiguous and provided a rather clear definition of TCK. However, she also talked about the overlap of technology and subject matter and raised the concern that technology varies greatly. Based on this concern, she doubted the validity of representing her (a teacher's) knowledge regarding technology with only one Venn diagram as she explains:

So if I create an overlap [of TK and CK] here this means that ... my technological knowledge can positively influence my content knowledge in the classroom, or support it, or something like this. (MARIANNE.00:03:20-2)

TPK. With regard to subject-general effects of technology on pedagogy, Heinz reported thinking about this sub-domain specifically. He also explicitly excluded subject-specific issues when thinking about his own developmental needs. The following quotes depict this:

I would like to know how, for example, I can facilitate the learning for students by means of technological tools. But I have to be careful not to take away too much from the pedagogical knowledge [by the TK overlap], because there are very many things that we cannot yet solve with technology. (HEINZ.00:04:27-7)

I lack knowledge in this area where I think about how to design technology rich situations in the classroom in a way that students actually learn something. I mean completely independent of the subject matter as well as depending on the subject. (HEINZ.00:07:20-9)

Marianne did not explicitly address subject-general effects of technology, which was interesting, because her representation of her next aspired state structure depicted a rather large TPK area (see Figure 3(b)).

TPACK. Marianne's characterization of the area where all sub-domains overlap was in line with the basic idea of the TPACK framework in that all sub-domains were intertwined in her GATI model. However, she only communicated a vague understanding of the concept. Additionally, she explicitly put her emphasis on PCK. These quotes demonstrate her understanding of TPACK:

[The area where all circles overlap] that would be like an ideal state; the place where everything relates to each other in a sensible way. (MARIANNE.00:04:58-4)

Well, content knowledge and pedagogical knowledge are somehow closer to each other than technological knowledge. (MARIANNE.00:04:35-2)

Heinz, however, reached a very different conclusion regarding the area where all basic sub-domains overlap. Instead of understanding the TPACK area as a comprehensive ideal knowledge, he explains it as very concrete, where all sub-domains are focused on a specific aspect, when he said, 'So what is an exciting question now, I ask myself what this [central] overlapping area represents. I believe that is the classroom instruction happening' (HEINZ.00:07:20-9).

How do participants determine circle size and overlap when creating their GATI?

Figures 2 and 3 depict replicas of the (a) current and (b) next aspired state GATI models as created by Heinz and Marianne. Size differences were more pronounced in both cases when the teachers created their current models. Differences between the participants were that Marianne chose a smaller circle for the TK to begin with, and also did not choose the largest circle for TK in her next aspired state representation. However, given her choice of a small circle as a starting point she actually depicted a larger developmental goal. In general, both agreed that larger circles, defined as expert-level knowledge, represent a desirable state for

teachers. Accordingly, both chose the largest circle for PK and CK in the next aspired state representation. The following quotes exemplify this finding:

In all areas it's ideal, when it's the largest circle, isn't it? (MARIANNE.00:06:00-6)

I think the relations [among the sub-domains] remain the same also in an ideal state; just everything a bit bigger. (MARIANNE.00:07:17-4)

Of course, I want to know everything. So I will put the largest circles here. One is still allowed to set himself some goals. (HEINZ.00:04:27-7)

Considering the positioning and overlap of the circles, the next aspired state representation of Heinz closely resembles the TPACK diagram introduced by Mishra and Koehler. However, considering that Heinz defined the central area as a concrete lesson in action instead of the overarching concepts of TPACK, the visual similarity may not represent the TPACK framework as intended by Mishra and Koehler (2006). Marianne created a much larger TPACK area, which can be attributed to her interpretation of this area representing the interconnection of all knowledge bases for her next aspired state model. Regarding TK, Marianne's next aspired state GATI figure seemed to relate to her statement that PK and CK are closer than TK because she positioned the three circles more horizontally and less equally distributed in space compared to Heinz (see Figure 3(b)). By doing so, however, she created a large overlapping area for TPK, without actually explaining its meaning. Her GATI had a very small TCK area, which matched her explanation. Heinz created a large area of TK separate from the other domains, while Marianne considered TK unrelated to the other professional knowledge. Marianne felt TK was less important as opposed to Heinz, who deemed TK itself as important and also created a distinct TCK area, emphasizing technology in relation to his subjects. Both created PCK as the largest overlapping area in their current GATI, and even larger in their next aspired state GATI. This could be related to German teacher training that specifically addresses pedagogy (German: *Fachdidaktik* = PCK).

How do participants' GATI models compare to their TPACK questionnaire data?

Both participants rated their confidence in the three TPACK domains as above average in all areas (see Table 2). Heinz assigned the highest rating of 5 to the TCK item and Marianne assigned the highest rating to the CK, PCK, and TCK items. Looking at the differences between ratings, Heinz reported relatively higher confidence in his TK ($\Delta = 1.2$ points on rating scale) and TPACK ($\Delta = 1.0$). In contrast, Marianne reported higher confidence in her PCK ($\Delta = 1.0$) and TPK ($\Delta = 0.6$).

Neither teacher chose the largest circle (6 cm) for PK or CK. This means, in contrast to the self-assessment using rating scales, there was no ceiling effect for the representation of these knowledge domains. Moreover, both teachers created a larger PCK area for their next aspired state GATI than in the current one, showing that using the GATI explicated the potential for professional growth that was not captured by the questionnaire items. This effect can be found for other knowledge domains as well. When comparing questionnaire data and GATI representations, self-descriptions differed significantly regarding the teachers' self-perceptions of their knowledge. Additionally, the questionnaire data suggested Heinz is slightly less knowledgeable in the basic domains whereas the circles he chose to represent his current knowledge structure suggested no such difference. Another puzzling finding is that Marianne, in contrast to rating herself as very knowledgeable in the TCK domain, did

not include a TCK area in her next aspired state knowledge structure. This shows that GATI also allows teachers to not include all sub-domains (overlapping knowledge bases) suggested by the TPACK framework. In sum, varying the size and overlap of circles enabled the participants to explicate and reflect on how the knowledge bases and sub-domains differ and what their integration could actually mean to them.

Q2: What insights about teacher learning can be obtained from completing the GATI process, and how might this inform a teacher's development of TPACK?

The two teachers were asked to describe their conceptions of professional development in TPACK and its respective knowledge bases to help researchers better understand any stages or phases in the development of TPACK. For both participants, two mechanisms were mentioned as prerequisites for professional learning: time and professional development. Although time is a very broad concept, for both Marianne and Heinz, time meant studying privately through self-regulated learning, that is, considering the meaning of what they had learned for their professional development. For Marianne, this included reading literature or reviewing the details of a technology, while for Heinz it meant learning about new aspects of his subjects or reading concise material about technologies. Overall, self-guided reading was a central method mentioned by both teachers and mainly concerning CK. However, Heinz added a specific aspect to his idea of time that suggests he views learning partly as a natural developmental process, namely *experience*. As he stated, the idea of experience is very strong in his reasoning about gaining PK:

Pedagogical knowledge expands by itself with time and with acting in the job. This happens by having an eye for the students [‘ issues] and by having enough time to develop a sense for what is wrong with the students and how to help them. In sum, I only need time and experience. (HEINZ.00:07:20-9)

In contrast, professional development can be identified as receiving new ideas from an external educator who models certain instructional strategies. Heinz described this type of professional development as a critical element for gaining integrated technological knowledge (TPK, TCK, and TPACK):

This area [integrated TK] is a typical issue to be addressed in a professional development course; someone demonstrating, for example, how a successful lesson with [technology] can look like. (HEINZ.00:07:20-9)

For Marianne, modeling is not only a way of learning about technology but also a necessary process for gaining PK. Although both participants consider PK an important aspect of their profession and their professional knowledge, their conceptions about how this knowledge can be developed differed greatly. Another interesting finding is that Marianne specifically connected professional development as learning that occurs with her colleagues, inferring collaborative learning is a characteristic of professional development as she explains, ‘[I can develop] Pedagogical knowledge during a pedagogical day or another PD with colleagues’ (MARIANNE.00:11:08-6).

For Marianne, motivation is a central issue for both time and professional development. She explained that time is needed for studying privately as well as formal professional development opportunities:

I need the drive, time as well, but also the drive to participate in more PD courses dealing with [technology]. Or to start reading about it privately. (MARIANNE.00:11:08-6)

And regarding technological knowledge also the interest, or actually also the peace and quiet outside of teaching to explore on my own how to plug in the boxes and how to calibrate them. (MARIANNE.00:11:08-6)

The uniqueness of the two participants' perceptions suggests there are many paths to develop TPACK. Results also indicated that these teachers feel the combination of self-regulated learning, as well as traditional professional development, are helpful processes within that development. Both teachers expressed the desire for more support in the area of technological knowledge development.

Discussion

In this article the Graphic Assessment of TPACK Instrument, known as the GATI, was introduced. The purpose of the study was to explore the usability of a tool based on a Venn diagram representation of the TPACK framework as a prompting technique for teachers to map their respective professional knowledge. The GATI was also used to help teachers reflect about learning paths as a potential base for their unique professional development needs. During this proof-of-concept study, the data showed that the process supported these teachers' meta-cognitive capabilities, and that the GATI was powerful in promoting teachers' individualized development and decision-making about technology integration in teaching and learning contexts. The GATI process helped the two in-service teachers who participated in this study explicate and reflect upon their understanding of the knowledge bases of the TPACK framework, and explain their personal theories about how knowledge in these domains could be developed. In review of the results, we found three areas that provided insight about TPACK development: visual exploration provided a prompt for reflection, the teachers had their own subjective theories of their TPACK development, and the GATI may have potential as a measurement instrument.

Visual exploration as a prompt for reflection

Concerning the structure of the TPACK framework, the findings of this study show that both teachers considered all three basic knowledge domains as relevant aspects of their professional knowledge. This is also true for the overlap of the sub-domains. Considering the emphasis on PCK in German teacher training, the results for this construct are not surprising. What adds to the discussion of the TPACK framework is the distinct specification of TPK and TCK, especially in one participant. Visually both teachers created TPK with considerable overlap, representing the idea that there are aspects of technology use in teaching that are subject-general (e.g. motivation). TCK remains somewhat ambiguous, although Heinz addressed this area extensively. This ambiguity is in line with Hofer and Harris's (2012) finding that teachers have difficulties grasping the TCK domain.

Based on these findings, we argue that the GATI procedure and the study presented here took a first step toward using the TPACK framework as an open-ended *practical* tool to prompt teachers to reflect on the personal perceptions of their professional knowledge. It stimulated reflective discussion and provided a path for the participants to engage in meta-cognitive development. In contrast to a self-report questionnaire, the GATI does not 'test' a person against an absolute ideal model (i.e. a lot of knowledge on all sub-domains or the ideal Venn diagram of the theoretical framework). Instead, the teachers create

subjective interpretations of their professional knowledge and thus provide a basis for development and individualized growth. Thus, the GATI as a tool can be used as a starting point and monitoring instrument of a teacher's professional development.

When looking at the study's results regarding the central 'TPACK' area, there were two contrasting perceptions reported by the participants: On the one hand, TPACK was viewed as overarching, integrated professional knowledge; on the other hand, it was perceived as arising from the concretization of more general professional knowledge. These results show that the ambiguity of the central area of the Venn diagram actually prompts an open-ended, think-aloud procedure. As the GATI allowed participants to give different interpretations, the use of the Venn diagram in this context seemed to actually deepen reflection. This is a great benefit with regard to the GATI as an ipsative (not a normative) measure of a teacher's professional knowledge and a tool to prompt reflection on the respective intra-individual learning processes. In addition, this ambiguity generates the need to further discuss ways to apply the TPACK framework to professional development. Research might focus on the individual teachers' interpretations of the theoretical conceptualization of how TPACK is structured, including the need to address meta-cognitive aspects more directly and how professional developers might best support the respective competencies (cf. Krauskopf, Zahn, and Hesse 2015; Michalsky and Kramarski 2015).

Participating teachers' conceptions of TPACK development

In terms of their development of TPACK, both teachers reflected about the tension between personal efforts (time and experience) and external support provided by professional development courses as ways to address their professional growth. Because the current literature does not provide clear guidelines as to how to recognize highly developed TPACK, it is difficult to evaluate which of the two participants is more developed. For example, Koehler, Mishra, and Yahya (2007) operationalize TPACK as more simultaneous references to TK, PK, and CK, whereas Cox and Graham define all sub-domains separately (Cox and Graham 2009). In addition, Angeli and Valanides (2009) claim that understanding the added value of a technology for teaching is TPACK, which gives less consideration to the sub-domains or overlapping areas of the model. Therefore, it makes sense that a graphic tool might support such inquiry.

Thus, if Heinz and Marianne were to be reviewed based on a developmental dimension of TPACK, the flexibility of size and relationship afforded by GATI allows for comparison among participants, as well as inferred change over time with one participant. Heinz talked in a more integrated manner about technology as he took the assessment, which would put him on a higher level of TPACK according to Koehler, Mishra, and Yahya (2007). He also specifically addressed TPK and TCK, which satisfies the categories of Cox and Graham (2009). Marianne also showed a complex understanding of how technology, pedagogy, and content can mutually influence one another, which falls in line with Angeli and Valanides's (2009) notion of added value. Still, the question remains as to whether a claim can be made that Marianne has less TPACK because she was not able to articulate what she would need to do to create added value for learning by means of technology.

Insight about the GATI process gained from this proof-of-concept study is just the beginning of a new line of research related to the development of TPACK, and prompts a call for an expanded line of future research to include: a more in-depth understanding of the

separate knowledge bases, a clearer definition of professional knowledge in the sub-domains, and knowledge about the interrelatedness and interactions of the sub-domains. On a practical level, the TPACK framework and the GATI process could be further developed and studied as a tool to foster a teacher's meta-cognitive development about their knowledge domains and decision-making processes about technology integration, and support of teachers through research-based professional development.

Potential of GATI as a measurement instrument

Concerning the proof of concept of GATI as a potential measurement instrument, varying the size and overlap enabled participants to explicate and reflect on how the three knowledge bases differed for them, how the knowledge bases interacted as sub-domains, and what that integration actually meant to them within their local context. Because GATI allowed teachers to exclude sub-domains suggested by the TPACK framework, the GATI method can be considered as less reactive or comparative to the standard TPACK model. The differences in the participants' definition of the sub-domains (see above) also showed that when using a self-report questionnaire, such differences in interpretation are not captured. Even though there were some obvious differences regarding the teachers' self-reported perceptions of their knowledge on questionnaire items, many differences captured by the GATI were not evident. It is, however, unclear whether a wider Likert scale would produce different results. This needs to be examined in future research.

This initial descriptive evidence indicates the GATI method provides a basis for self-guided and other-guided reflection of the professional knowledge teachers need based on the TPACK framework. In order to validate the GATI as a measurement in the development of TPACK, further research is needed: to connect the visual representations and think-aloud protocols to teachers' actual practice or at least their performance in lesson design tasks (cf. Angeli and Valanides 2009; Kramarski and Michalsky 2010; Krauskopf, Zahn, and Hesse 2012), to explore the convergent and discriminant validity of the parameters of variation in size and overlap with questionnaire data using larger sample sizes, and to determine how valid quantitative parameters could be derived from the GATI representations.

Conclusion

The authors of this study conceptualized the GATI to be a graphic tool to support individual teachers in reflecting on their professional knowledge (meta-conceptual awareness), as well as on their professional development needs, in order to progress toward more effectively teaching with technology. The presented tool uses a Venn diagram construct, with dynamic size and overlap, that prompts teachers to reflect about their teaching practice and the influence of their local context, especially where the use of technology is concerned. The findings illustrated that using the GATI process: (1) pinpointed teachers' conceptualizations of their current professional knowledge (meta-conceptual awareness), (2) helped the teachers identify their next aspired state, and (3) elicited verbal explanation of teachers' perceived knowledge and development. Thus, the current results practically and theoretically contribute a new approach to the discussion surrounding the importance of meta-cognitive competencies as central components of TPACK (Kramarski and Michalsky 2010; Krauskopf, Zahn, and Hesse 2015; Michalsky and Kramarski 2015). It also provides a basis to study a teacher's

understanding of their professional knowledge, and to assist them in identifying their professional developmental needs.

Due to the imprecision inherent in data collected from experiences of the two participants, the results do not necessarily generalize beyond this experience, but can be viewed as an initial and in-depth exploration meant to inform the larger design of the GATI process as well as to inform future research. The data establish the feasibility of the GATI for use as a tool for prompting teachers' reflection about their technology knowledge. This study marks the beginning of a new way of viewing the development of TPACK and calls for the research community to improve the theoretical understanding of what constitutes an expert teacher in the area of TPACK and how to best support teachers in their development. To this end, the authors of this study invite others to use the GATI model and share their insight.

Disclosure statement

No potential conflict of interest was reported by the authors.

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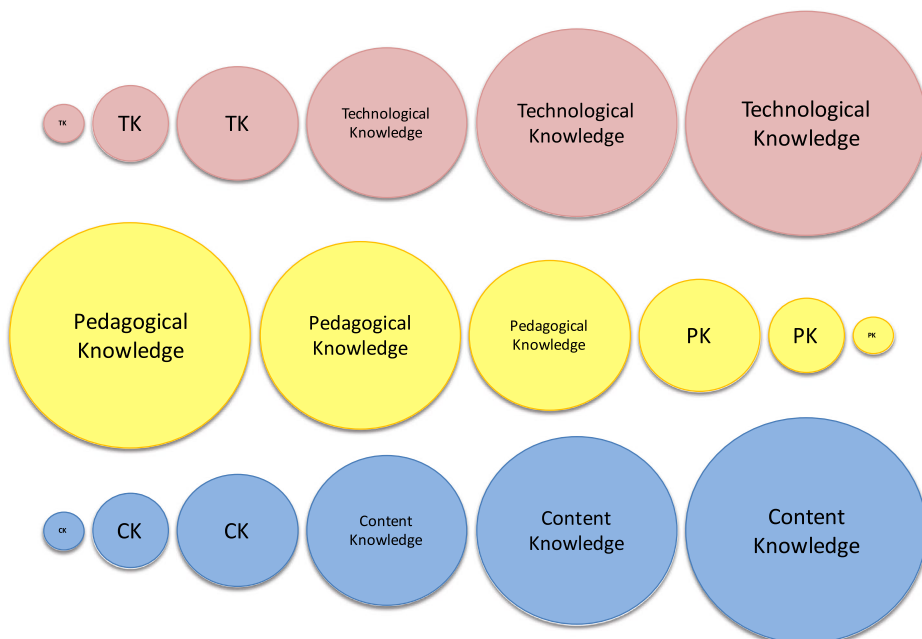
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Appendix 1. GATI template for printing circle manipulatives



Appendix 2. English translation of the GATI procedure

Here we have *circles of different sizes*. They represent the knowledge domains pedagogy/general didactics, content/curriculum, and technology.

Current status

- (1) Please choose a circle for each knowledge base that represents *your current stage of knowledge in each domain*.
- (2) Please make sure that the circles you chose fulfill the following criteria. If a circle you chose does violate a criterion, please adjust your choice accordingly.
 - (a) The smallest circle stands for the level of a lay person's knowledge, the largest one for that of an expert (following your own definition of expertise).
 - (b) The size of the different circles should represent your 'level of expertise' in the different domains in relation to each other. So, for example, if you think that your general pedagogical knowledge is twice as developed as your content/curriculum knowledge, you would choose a circle that is also twice the size to represent this domain.
- (3) Now, please position the circles in relation to each other. The goal is to represent the relation of the different knowledge domains to each other *as it is the case for you from your own personal perspective*.

Ideal status

- (1) Now, please choose for each knowledge domain a circle that represents *an ideal level of your knowledge in the respective domain*.
- (2) Please make sure that the circles you chose fulfill the following criteria. If a circle you chose does violate a criterion, please adjust your choice accordingly.
 - (a) The smallest circle stands for the level of a lay person's knowledge, the largest one for that of an expert (following your own definition of expertise).
 - (b) The size of the different circles should represent your 'level of expertise' in the different domains in relation to each other. So, for example, if you think that your general pedagogical knowledge is twice as developed as your content/curriculum knowledge you would choose a circle that is also twice the size to represent this domain.
- (3) Now, please position the circles in relation to each other. The goal is to represent the relation of the different knowledge domains to each other *as it ideally should be from your own personal perspective*.

Prompt for reflection

Please think aloud about the questions below. Say out loud every thought that comes to your mind without judging it. Please keep on talking while you are working on the tasks. Act as if you were on your own and think for yourself.

- (1) Which knowledge do you lack?
- (2) What do you need to develop your knowledge?

- (3) What kinds of support would you need for that? How do you imagine the support that helps you reach the ideal status you depicted?
- (4) What kinds of support are available to you at the moment?

Appendix 3. German version of the GATI procedure used in this study

Wir haben hier *Kreise* unterschiedlicher Größe, die für die drei Wissensbereiche Pädagogik/allgemeine Didaktik, Fachinhalt und Technologie stehen.

Gegenwärtiger Status

- (1) Bitte wählen Sie für jeden Wissensbereich einen Kreis aus, *der Ihr momentanes Wissen in der jeweiligen Domäne repräsentiert.*
- (2) Stellen Sie nun bitte sicher, dass die von Ihnen gewählten drei Kreise die folgenden Kriterien erfüllen. Falls sie das nicht tun, ändern Sie Ihre Wahl bitte entsprechend.
 - (a) Der kleinste Kreis steht für das Niveau eines absoluten Laien, der größte für das Niveau eines Experten (nach Ihrer persönlichen Definition von Expertise).
 - (b) Die Größen der Kreise sollten Ihre 'Expertise' in den unterschiedlichen Domänen relative zueinander widerspiegeln, also z.B. wenn Sie denken, dass Ihr pädagogisches Wissen doppelt so entwickelt ist, wie ihr Fachwissen, dann sollte der entsprechende Kreis ebenfalls doppelt so groß sein.
- (3) Bitte positionieren Sie nun die Kreise in Beziehung zueinander. Das Ziel ist, die Relationen der Wissensbereiche zueinander so darzustellen, dass sie wiedergeben, *wie es nach Ihrem Empfinden derzeit bei Ihnen der Fall ist.*

Idealer Zielzustand

- (1) Bitte wählen Sie für jeden Wissensbereich einen Kreis aus, der repräsentiert, *wie Ihr Wissen in der jeweiligen Domäne idealerweise aussehen sollte.*
- (2) Stellen Sie nun bitte sicher, dass die von Ihnen gewählten drei Kreise die folgenden Kriterien erfüllen. Fall sie das nicht tun, ändern Sie Ihre Wahl bitte entsprechend.
 - (a) Der kleinste Kreis steht für das Niveau eines absoluten Laien, der größte für das Niveau eines Experten (nach Ihrer persönlichen Definition von Expertise).
 - (b) Die Größen der Kreise sollten Ihre 'Expertise' in den unterschiedlichen Domänen relative zueinander widerspiegeln, also z.B. wenn Sie denken, dass Ihr pädagogisches Wissen doppelt so entwickelt ist, wie ihr Fachwissen, dann sollte der entsprechende Kreis ebenfalls doppelt so groß sein.
- (3) Bitte positionieren Sie nun die Kreise in Beziehung zueinander. Das Ziel ist, die Relationen der Wissensbereichen zueinander so darzustellen, dass sie wiedergeben, *wie die Beziehungen idealerweise sein sollten.*

Aufforderungen zur Reflexion

Bitte denken Sie laut über die folgenden Fragen nach. Sprechen Sie jeden Gedanken aus, der Ihnen kommt, ohne ihn zu bewerten. Bitte sprechen Sie während der Beantwortung immer weiter. Tun Sie so, als wären Sie allein und würden für sich überlegen.

- (1) An welchem Wissen fehlt es Ihnen?
- (2) Was brauchen Sie, um Ihr Wissen zu erweitern?
- (3) Welche Unterstützung benötigen Sie dafür? Was können Sie sich vorstellen, welche Unterstützung Ihnen hilft Ihr Ziel/diesen Idealzustand zu erreichen?
- (4) Welche Unterstützung steht Ihnen im Moment zur Verfügung?