SECONDARY TEACHERS' PEDAGOGICAL REASONING FOR USING TECHNOLOGY IN MATHEMATICS LESSONS: AN EXPLORATIVE STUDY

B. Cabbeke[1], T. Rotsaert[1], T. Schellens[1]

[1]*Ghent University (BELGIUM)*

Abstract

Recently, scholars have started unpacking teachers' technology-related decision-making via the conceptual lens of pedagogical reasoning. Answering to the call for more domain-specific reasoning studies, this study explores secondary school mathematics teachers' pedagogical reasoning underlying their technology-mediated practice. By means of an open-ended survey, 30 Flemish secondary school mathematics teachers' technology integration practices were explored. Results show that teachers strongly value technologies that help them in (a) efficiently managing teaching and/or learning activities or (b) effectively attaining learning goals and meeting students' learning needs. In contrast, technology-usage to engage or extend students' learning was limited. In addition, although teachers report using a plethora of different type of technology tools, teachers most frequently mention using mathematical action tools, which help them to visualise mathematical ideas as well as to save time during instruction. To conclude, this study puts forward theoretical recommendations for future research as well as practical suggestions to foster (student-)teachers pedagogical reasoning.

Keywords: Pedagogical Reasoning, ICT, Technology Integration, Mathematics Education, Teacher decision-making, Secondary Education

1 INTRODUCTION

1.1 The integration of technology in education

Implementing technology in the classroom has the potential to create more engaging, effective and/or efficient teaching and learning processes [1,2]. However, the promise of technology for education and teachers' actual use of technology in practice are often not aligned [3]. A possible explanation for this phenomenon lies in the barriers teachers face during their technology-integration efforts, such as a lack of resources, school leadership, technological knowledge, and IT support [4,5]. Scholars emphasize the importance of fostering teachers' ability to juggle existing constraints by strengthening their professional technology-related competencies [6,7]. In this regard, decades of research studies focused on the relation between (a) teachers' technology-related knowledge, often using the technological pedagogical content knowledge (TPACK) conceptual model of Mishra and Koehler [8], (b) teachers' tacit non-rational dispositions (i.e., pedagogical beliefs, ICT attitudes, openness to change) [9], and (c) teachers' successful integration of technology in learning and instruction [10,11]. However, to further unpack teachers' technology-mediated practices and their connection to teachers' TPACK and dispositions, scholars have recently begun to focus on teachers' decision-making processes in the context of technology integration [1,12–16]. Within this emerging research field, the concept of 'pedagogical reasoning' is often being used as a conceptual lens to analyse teachers' technology-related decisional processes [1, 16–18].

1.2 Pedagogical reasoning in the context of technology

1.2.1 Pedagogical reasoning

Pedagogical reasoning (PR) refers to the "thinking that underpins informed professional practice" [19, p.4]. In his theoretical framework 'Pedagogical Reasoning and Action' (PR&A), Shulman [20] coined the concept of pedagogical reasoning, which he depicts as a dynamic, cognitive process of six stages that teachers go through in order to teach. These six stages include (1) comprehension (of what is to be taught, the context, and the purposes for teaching); (2) transformation (of the content, into conceptual models, learning activities, and adaptations to specific learners' characteristics); (3) instruction (the observable acts of teaching); (4) evaluation (of students' learning and teacher's instruction); (5) reflection (on classroom experiences); and (6) new comprehensions. Each stage represents a different area on which a teacher should be able to reason to make effective pedagogical decisions [16, 20]. Building on Shulman's broad description of PR&A, Forkosh-Baruch and colleagues recently proposed a revised definition, defining pedagogical reasoning as 'an ongoing process by which teachers develop and articulate theoretical and/or practical understanding to describe why, what & how their practices lead to sustainable learning' [21, p.12]. Three aspects in this definition are central to PR. First, through planning and enacting soundly reasoned classroom experiences and reflecting on them, teachers develop new *understandings* that add to their existing knowledge base [19]. In other words, PR not only draws upon teachers' professional knowledge, but also add to it [12]. Second, when teachers make their reasoning explicit by *articulating* the why of their practice, they give insight into their professional knowledge. As this knowledge is often tacit in nature, PR offers a way to unpack the unseen aspects of practice [19]. Lastly, with *sustainable learning* at its core, PR differs from other types of teacher' thinking and decision-making that are based purely on efficiency in the classroom or managerial aspects of classroom practice [21].

1.2.2 Pedagogical reasoning underlying teachers' use of technology

As effective teaching with technology is not simply the addition of technology into existing classroom activities, but imply a considerate use of technology [22], scholars have recently started emphasizing the importance of solid PR in the context of technology integration [16]. According to recent research [17, 23-24], there is a wide variety of rationalizations underlying teachers' usage of technology. For example in the context of secondary history education, Voet and De Wever [24] found four types of rationales underpinning teachers' adoption of technology tools: (a) increasing effectiveness of instruction, (b) increasing work efficiency, (b) connecting to everyday life, and (d) complying with expectations from others (e.g., school leader, colleagues). Moreover, teachers' technological practices tended to be teacher-centric with little active technology use by students. On the contrary, in the study of Hughes et al. [17] teachers were prone to use technology in a more student-focused matter. In addition, they found that teachers mostly value technology for its ability (a) to facilitate students' knowledge and skill development, (b) to support visual needs, (c) to tailor learning towards students' needs, and (d) to increase efficiency as well as to monitor students' progress during grading and assessment. In the study of Heitink et al. [11], teachers commented on the reasoning behind their technology-use in practice. Teachers' main reasons to use technology are to (a) make learning attractive for students, (b) realize educational goals, and (c) facilitate the learning process. In line with Voet and De Wevers [24] findings, teachers' technology usage primarily showed aspects of the knowledge transfer model of teaching. Overall, the technology-related rationalizations found in the abovementioned studies are in line with the suggestion of Kopcha et al. [15] that a teacher's use of technology is *value-driven*, in which teachers decide to use technology to efficiently and effectively manage their professional responsibilities, such as addressing learning needs and reaching learning goals in the classroom.

1.3 A discipline-specific exploration of teachers' technology-related pedagogical reasoning: the case of secondary school mathematics

Although PR-related research is emerging, teachers' reasoning about their technology usage is still not adequately understood [25], and more research is warranted to better grasp this concept [18]. More specifically, research signals a need for more discipline-specific reasoning studies [17]. This is especially the case for the domain of secondary school mathematics in which only few studies have been conducted [26-27]. Within this context, the study of McCulloch et al. [28], in which they explored the technology-related decision-making of 21 early career secondary mathematics teachers, is worth mentioning. They found that teachers do not immediately choose a specific technology that is appropriate for a learning goal. Instead, teachers first determine which broader type of technology they should use. Types of tools that teachers in their study mention using in their classroom practices spanned mathematical action tools, collaboration tools, assessment tools, and communication tools. Concerning teachers' reasons to use technology in mathematics education, McCulloch et al. [28] found that teachers value technologies' ability to provide opportunities to build understanding as well as provide opportunities to practice or review important mathematical concepts. With regards to building understanding, technology can support students in comprehending a mathematical idea or procedure. In addition, technology can automate procedures or generate examples quickly, which saves time during instruction and helps students to focus on what they are supposed to learn. In terms of providing opportunities to practice or review important mathematical concepts, teachers report they chose technology because it could offer students an engaging activity as well as immediate feedback.

In this study, we want to adhere to the call for more discipline-specific reasoning studies by examining how Flemish secondary school mathematics give meaning to their technology-mediated teaching and learning activities. More specifically, we explore which type of technologies teachers use (a), how technologies are used (b), and which PR underpins these technology-mediated activities (c).

2 METHODOLOGY

2.1 Participants

A total of 30 secondary Mathematics teachers participated in this study. They voluntarily participated in this study by responding to a region-wide call distributed in February 2020 to Flemish secondary schools. On average, participants were 44,28 years old (*SD* = 10,16 years), with a minimum of 26 and a maximum of 66 years. Of this sample, 54,8% (*n = 17)* was female and 45,2% (*n* = 14) male. Participating teachers have, on average, 17,3 years (*SD* = 9,79 years) of expertise in teaching mathematics in secondary schools, with a minimum of 2 years and a maximum of 38 years. In addition, as our participants voluntarily accepted the region-wide call for participation, which explicitly called for teachers who regularly use ICT in their secondary school mathematics practice, teachers in our sample are possibly more positive, knowledgeable, and/or confident regarding their use of technology in education than the average teacher.

2.2 Data collection

Participants were invited to complete an online, open-ended survey which explored their reasons underlying their technology-mediated classroom activities. As part of this survey, mathematics teachers were asked to describe a maximum of three technology-enhanced learning or teaching activities they themselves find very valuable. For each activity, teachers addressed (a) a specific technology, (b) the subject matter in which the technology is frequently used, (c) the classroom activities within which the technology is deployed, what role the technology plays in these activities, and who uses the technology (teacher/student), and (d) the reason(s) why the teacher chose to use the technology in their teaching practice (i.e., its added value). In total, 85 technology-mediated activities were collected and analyzed.

Prior to data collection, interpretations of survey questions were validated through interviews with three mathematics teachers who filled out the survey. Some questions in our survey were rephrased based on their feedback regarding the instructions and used terminology.

2.3 Data analysis

Prior to unpacking teachers reasoning underlying their technology-mediated practices, we categorized their classroom practices by the type of technology mentioned. The four distinct types of tools identified in McCulloch et al. [28], namely (a) mathematical action tools, (b) collaboration tools, (c) assessment tools, and (d) communication tools, provide a valuable starting point to categorize teachers' classroom practices. For each identified category, several analyses took place. To start, we identified statements that involved an expression of either how technology was used or why it was used. Next, similar to other studies [11, 17, 24], we analyzed how technology was used by coding whether the usage of technology was related to a knowledge transfer (KT) of knowledge construction (KT) pedagogical approach. Activities relating to KT include but are not limited to whole classroom teaching, drill and practice of knowledge, summative and formative assessment, direct feedback on correctness. KC activities are characterized by activities which relate to problem solving or inquiry learning, in which students have an active role in (collaboratively) constructing knowledge and assessing their own learning. In comparison to KT, students oversee their own learning activities and teachers predominantly adopt the role of a guide.

To analyze the statements in which teachers express their reasoning underpinning their technology use, we used two distinct coding cycles. First, we used an open-coding process in which emic and etic coding categories and definitions emerged, whilst constantly comparing our codes and coded date to ensure consistency [29]. Second, we adopted Kolb's [2] Triple E framework to analyze whether teachers decide to use technology to enhance, extend, or engage students' learning. In line with Kopcha et al. [15] suggestion, we also added a fourth E – efficiency – in our coding process, as teachers also value using technology to perform certain tasks in the classroom more rapidly (e.g., efficiently distribute materials to students). To add to the trustworthiness of our coding, the co-authors of this paper coded the data with regular code checking between researchers until 100% agreement on codes was achieved [29].

3 RESULTS

The 30 secondary mathematics teachers described a total of 85 technology-mediated classroom activities, which were categorized in seven distinct categories: mathematical action tools; presentation tools; instructional software and media; assessment tools; communication tools; system of integrated tools; and collaboration tools. Table 1 shows the distribution of the activities within these categories. Primarily, teachers' described activities in which they use mathematical action tools (52,9%). In contrast, no activities were mentioned in which collaboration tools were used.

Table 1. Frequencies of type of technology tools mentioned in teachers their technology-mediated learning activities.

Type of technology tools	*n*	%
1. Mathematical action tools	45	52,9
2. Presentation tools	15	17,6
3. Instructional software and media	13	15,3
4. Assessment tools	8	9,4
5. Communication tools	2	2,4
6. System of integrated tools	2	2,4
7. Collaboration tools	0	0,0
Total frequency	85	100,0

Teaches dominantly describe using technology in activities that relate to a knowledge transfer model of teaching and learning (84,7% of the activities). In contrast, only 15,3% of the activities corresponded to the knowledge construction model of teaching. In terms of teachers' reasoning descriptions, we found that teachers' decision to use a technology is most frequently underpinned by an efficiency logic. Efficiency-type rationalizations were mentioned in the reasoning descriptions of 44,7% of the activities. To a lesser extent, teachers' reasoning descriptions related to Triple E rationalizations: enhancement (34,1 % of the activities), engagement (10,6% of the activities), and extension (11,8 % of the activities). Important to note is that 23 of the 85 analyzed activities described reasoning descriptions which mentioned multiple E-rationalizations. In addition, 20% of the activities lacked sound reasoning descriptions and could not be categorized in any of the E-categories (e.g., using technology because it is a requirement in the Flemish curriculum standards or because the technology is easy in use, reliable, or accessible in the classroom). In the sections below, we discuss teachers' PR to use technology in more detail. Important to note is that, during the analysis, we discovered similarities in teachers' reasoning when describing tools from within the same category. Therefore, in the section below, we describe the most common reasons underlying the usage each different type of technology identified in this study.

3.1 Mathematical action tools

Mathematical action tools refer to tools or software that are able to "perform mathematical tasks and/or respond to the user's actions in mathematically defined ways" [30, p. xii]. Within this category, teachers in our survey mention the use of GeoGebra, graphic calculators, and spreadsheet software.

The integration of GeoGebra was the most mentioned technological tool. More specifically, 26 of the 30 teachers mention the use of GeoGebra as one of their three technology-mediated activities. Classroom activities with this software were described for a range of topics, spanning geometry, algebra, and statistics. In approximately two thirds of these activities, students passively observe how teachers use this software during instruction. In contrast, one third of this subgroup describe in which students use GeoGebra for computation, examining mathematical properties, or analyzing data or graphs. With regards to reasoning, most teachers (81%) note valuing GeoGebra for its ability to visualize (abstract) mathematical ideas and properties, which aid students in understanding the subject matter (i.e., enhancement). For example, a teacher described how they could foster students' understanding of a simple geometric relationship – the sum of the angles of a triangle is 180 degrees – by quickly generating and dynamically adjusting geometrical objects. In addition, ten teachers also report that GeoGebra helps to save time during instruction (i.e., efficiency), either by being able to illustrate mathematical ideas quicker via dynamic visualizations or by reducing time spent on manually constructing graphs of geometric objects on the whiteboard. Interestingly, three teachers note using GeoGebra as a substitute for the graphic calculator, whilst indicating that their schools transitioned from obligating students to purchase graphic calculators to students' using this free software on their own laptop.

The graphic calculator is the second most mentioned tool (18 of the 30 teachers). In contrast to GeoGebra, teachers predominantly describe students' actively using this tool in class for a range of activities (e.g., creating graphs of functions, computation of complex operations). As teachers describe students having their own graphic calculator, it could be argued that the prevalence of this technology could underpin why teachers report students' active use of this tool. In line with GeoGebra, teachers value graphic calculators in visualizing mathematical ideas, concepts, and relationships (i.e., enhancement). An example of this is using the calculator to graph the derivative of a function. In addition, teachers their reasoning also depicts using calculators in class as an opportunity to reduce (unnecessary and/or difficult) computation or construction of graphs by hand. This not only saves time during lesson (i.e., efficiency), allowing students to make additional exercises or receive additional feedback, it also allows students to focus on mathematical reasoning to make sense of (complex) examples or (word) problems (i.e., enhancement). In other words, offloading computation or construction to calculators allows students to focus on reaching the goal of the lesson. In addition, several teachers note that they find it important that students develop the attitude to check their solutions (i.e., extend).

Lastly, spreadsheet software was mentioned by two teachers in which students actively use this software to solve exercises in the discipline of Statistics. One teacher argues that the use of spreadsheet software helps to quickly generate charts (i.e., efficiency) as well as helps to develop students ICT-skills (i.e., extend). The other teacher vaguely reports that using spreadsheet software aids in reaching lesson goals but does not explicitly state how or why the technology helps.

3.2 Presentation tools

We refer to presentation tools as programs or software that can be used to either statically or interactively display digital media. In the analyzed activities, teachers mention using interactive eBooks developed by educational publishers (6 teachers), note-taking apps such as Microsoft OneNote, Google Jamboard or Notability (6 teachers), and PowerPoint (3 teachers). All the activities within this category describe teachers using these tools during instruction to transfer knowledge. Results show that the use of this type of technology is predominantly grounded on an efficiency-type of reasoning in which teachers argue that these tools save time during instruction as teachers don't need to manually write on the whiteboard and teacher's notes can be shared with students. Moreover, the added structure that digital media provides would make it easier for students to follow the lesson properly. In addition, teachers also mention that using e-books or presentation software makes it possible for them to pace around the classroom more freely and monitor students more easily. The use of note-taking apps is mainly used as a digital substitute of the traditional whiteboard during online teaching. Two teachers valued presentation tools because they felt it keeps students engaged.

3.3 Instructional software and media

Activities within this category include the use of instructional videos (e.g., Wezooz Academy, KhanAcademy, YouTube) or digital content-specific learning environments (e.g., Diddit, Classcraft). The pedagogies underlying the activities in this category all relate to the knowledge transfer model of learning, in which students either passively receive instruction or focus on drill and practice of knowledge. The use of these types of tools are valued by teachers because they aid in adhering to students their learning needs. Learning environments, for example, provide students with opportunities to practice concepts at their own pace and competency level (i.e., enhancement), whereas instructional videos offer students agency over their learning process as they can pause, fast-forward or rewind aspects of an instructional video. Moreover, teachers value both in its opportunity to act as a teaching aid in the classroom (e.g., allowing teachers to focus on providing additional support to individual students) as well as its opportunities to move learning outside of the classroom (i.e., extend). Lastly, several teachers also mention valuing these types of software because they offer engaging activities for students (i.e., engaging), whilst providing immediate feedback to both students as teachers. Thus, offering opportunities to for both students as teachers to monitor learning processes (i.e., enhancement).

3.4 Assessment tools

Eight teachers mention using assessment tools, specifically Kahoot!, BookWidgets or Socrative, for both formative as summative assessment purposes. Five teachers note the opportunities these tools provide to quickly and easily keep track of students' understanding of the goals, informing them about which students need additional support (i.e., enhancement). In addition, three teachers also describe how using these tools reduce time spent on grading (i.e., efficiency). Lastly, two teachers mention that assessment tools offer a fun alternative to review concepts at the end of a lesson (i.e., engagement).

3.5 Communication tools and system of integrated tools

Only two teachers mention using communication tools, specifically Microsoft Teams. Both teachers state using Teams to efficiently converse as well as share digital resources (e.g., tasks, answer keys) with students (i.e., efficiency). Teachers disclosed these practices originated from their online teaching practices during Corona.

3.6 System of integrated tools

Lastly, two teachers also describe using the Google Workspace for Educational Fundamentals, which provides a set of education tools from Google. More specifically, both teachers describe how this workspace helps them perform a range of tasks, including sharing learning tasks via Google Sites, collecting assignments via Google Classroom, conducting assessments via Google Forms, providing instruction via Google Sheets, etc. One teacher describes how the use of these tools are engrained within the pedagogical approach of the entire school, in which students take ownership over their own learning (i.e., engagement) and teachers act as coaches. The other teacher mentions the use of these tools in a more traditional pedagogical approach during online teaching, valuing these tools for preparing students for the future work environment, in which similar type of integrated application are ubiquities (i.e., extend).

4 CONCLUSIONS

The aim of this study was to explore secondary mathematics pedagogical reasoning underlying their most-valued technology-mediated practices. Getting insight in how teachers reason about their technology usage sheds further light on teacher's technology integration processes. In this study, we identified which types of tools secondary mathematics teachers use. From the results it is clear that, although teachers mentioned a variety of tools, almost all teachers mention using mathematical action tools such as GeoGebra or graphic calculators, indicating that these tools are strongly valued among many mathematics teachers. Mathematical actions tools are praised for providing opportunities to foster students' understanding of the learning goals by visualizing (abstract) mathematical concepts. In addition, we also found that teachers strongly value these types of tools because they help to save time during lessons (e.g., eliminating unnecessary computation or construction). This result ties well with McCulloch et al. [28] which showed teachers valuing technologies' ability to provide opportunities to improve students' mathematical understanding via delegating procedures to technology, generating examples quickly, and supporting students' sense-making of mathematical ideas.

Another significant finding with regards to teachers' PR was the extent to which the teachers dominantly reason from an *enhancement* or *efficiency* standpoint to explain the value of their technology usage. Surprisingly, *engagement* or *extension* type of rationalizations were limited. These results suggest that mathematics teachers prioritize technologies that help to manage their professional responsibilities effectively or efficiently. These findings are in contrast with Heitink et al. [11] who showed that most teachers use technology to make the learning process more attractive and motivating for students. We speculate that this difference may be due the fact that our study adopted a domain-specific focus on secondary mathematics. In this light, it could well be that the very nature of teaching secondary mathematics triggers teachers in looking for ways to support students' understandings of complex mathematical concepts, relationships, and ideas by adopting technologies which aid in enhancing students' learning either directly or indirectly via efficiency-grounded technology usage (e.g., freeing up time to spend on additional practice or feedback).

Concerning the high prevalence of efficiency-type rationalizations in our study, one could question to what extent these efficiency-related type of reasoning can be categorized as PR. For example, Forkosh-Baruch et al. [21] their revised definition of PR (mentioned above) refers to PR as reasoning that has sustainable learning at its core, clearly excluding all types of reasonings that are based purely on efficiency. In contrast, similar to the findings in our study, other studies have reported that teachers find technology effective when it helps them manage their classroom activities more efficiently, helping them free up valuable time to engage students more deeply in the subject matter [15, 28]. Concerning this issue, we argue that there is a need for nuance, in which a distinction should be made between (a) teachers deliberately deciding to use technology to free up time which could be spent on, for example, additional practice and review, and (b) efficiency type of reasonings that do not have a subordinate pedagogical goal in mind (e.g., reducing time on manual grading, having quick access to other teachers' resources). Although teachers can find value in both types of technology use, we argue that the former type of efficiency-reasoning originate from a subordinate pedagogical intention and, consequently, should also be considered as PR.

With regards to how technology was used, results dominantly show mathematics teachers using technology within a knowledge transfer pedagogical approach. Moreover, in this study, not one teacher described the use of collaboration tools in their practice. These findings are in accordance with other studies reporting that teachers mostly use technology in traditional, teacher-centered practices [6,11]. Research often problematizes the dominance of this traditional pedagogical approach, whilst favoring a knowledge construction pedagogical approach for technology-rich education [1,6]. Scholars have recently begun to steer away from overly focusing on this single dimension of technology integration, as equating effective technology integration with (just one) pedagogical approach is problematic [15]. Regarding this discussion, we agree with the suggestion of Kopcha et al. [15] that, in order to generate a complete understanding in the complexities of teachers' technology-integration, we should place greater focus on unpacking the process of teachers' decision-making when they are considering how technology can help them to address learning needs and achieve learning goals within an unique school context. In the limitations below, we put even more stress on this issue by highlighting the importance of focusing on examining the process of teachers' PR.

There are some limitations to this study. First, to determine teachers' PR on using technology in mathematics, we used a survey with open-ended question in which teachers could describe the reasoning underpinning three of their technology-mediated classroom activities. However, capturing reasoning in this manner could have restricted teachers to fully disclose their technology-integration practices. For example, teachers were asked to describe which technology they use in a specific classroom activity, indirectly limiting them in discussing how they possibly use multiple technologies in concert. With regards to this, research mentions that teachers often use multiple technology tools at once during a single lesson [1, 28]. We argue that the use of qualitative interviews could provide more accurate and richer descriptions of how and why teachers decide to use (a combination of) certain technologies within their unique school context.

A second limitation focuses on our examination of PR. Via survey questions, we prompted teachers to share their PR in a retrospective manner. That is, reflecting on the added value of existing technology-mediated activities. However, this did not capture the in-process reasoning that a teacher went through when they originally designed, implemented, and evaluated their technology-mediated activities. Hence, our approach to examining PR only offers a limited window into teachers' entire technology-integration processes. Moreover, teachers' reasoning is known to be tacit in nature [19]. Consequently, the reasoning depicted from our data could perhaps only show a fraction of the reasons teachers adhere to their technology-rich classroom practices. This may also explain why a fifth of the analysed activities in this study did not include any sound PR. To fully unpack teachers' technology-related decision-making, we recommend research to further unpack the thinking processes teachers go through whilst designing, enacting, and evaluating new technology-mediated practices. Unpacking PR in this manner could help shed light on how decisions are made whilst being mindful of broader contextual constrains [15]. A valuable starting point to this aim, is the use of theoretical models which updated Shulman's original PR&A process model to account for teachers' technology-integration behaviours [16].

Our study generated important results as the literature on PR about technology is still limited, and there is an almost complete dearth of research which focuses on the teachers' PR in the context of secondary school mathematics. The pedagogical uses of (different types of) tools identified in this study could benefit other (student-)teachers in their technology-integration processes. Hence, sharing in-service teachers' reasoning with (student-)teachers in professional development initiatives (PDIs) may stimulate them to consider the benefits that different types of technology tools have to offer [17, 25]. In addition, we are one of the first studies that analyse teachers' technology-related decision-making via Kolb's Triple E's with a fourth E, Efficiency. We suggest using these 4E's in PDIs as it provides a clear and robust framework to let (student-)teachers reflect on their technology-mediated practices. In addition, it may nudge them to integrate technology to incorporate one or multiple E's. An added benefit of using the 4E's in PDIs that it allows (student-)teachers to reason about their usage of educational technology, without positioning one pedagogical approach as being superior to another [15]. Ultimately, we believe that these professional development suggestions may stimulate teachers into reasoning more soundly on their integration of technology in the classroom.

REFERENCES

[1] M. L. Niess and H. Gillow-Wiles, "Expanding teachers' technological pedagogical reasoning with a systems pedagogical approach," *Australas. J. Educ. Technol.*, vol. 33, no. 3, pp. 77–95, 2017, doi: 10.14742/ajet.3473.

[2] L. Kolb, *Learning first, technology second: The educator's guide to designing authentic lessons*. International Society for Technology in Education, 2017.

[3] J. Fraillon, J. Ainley, W. Schulz, T. Friedman, and D. Duckworth, "Teaching with and about information and communications technologies," in *Preparing for Life in a Digital World: IEA International Computer and Information Literacy Study 2018 International Report*, Cham: Springer International Publishing, 2020, pp. 175–214.

[4] E. Y. K. Loong and S. Herbert, "Primary school teachers' use of digital technology in mathematics: the complexities," *Math. Educ. Res. J.*, vol. 30, no. 4, pp. 475–498, 2018, doi: 10.1007/s13394-018-0235-9.

[5] P. A. Ertmer, "Addressing first- and second-order barriers to change: Strategies for technology integration," *Educ. Technol. Res. Dev.*, vol. 47, no. 4, pp. 47–61, 1999, doi: 10.1007/BF02299597.

[6] P. A. Ertmer, A. T. Ottenbreit-Leftwich, O. Sadik, E. Sendurur, and P. Sendurur, "Teacher beliefs and technology integration practices: A critical relationship," *Comput. Educ.*, vol. 59, no. 2, pp. 423–435, 2012, doi: 10.1016/j.compedu.2012.02.001.

[7] F. A. Inan and D. L. Lowther, "Factors affecting technology integration in K-12 classrooms: A path model," *Educ. Technol. Res. Dev.*, vol. 58, no. 2, pp. 137–154, 2010, doi: 10.1007/s11423-009-9132-y.

[8] P. Mishra and M. J. Koehler, "Technological pedagogical content knowledge: A framework for teacher knowledge," *Teach. Coll. Rec.*, vol. 108, no. 6, pp. 1017–1054, Jun. 2006, doi: 10.1111/j.1467-9620.2006.00684.x.

[9] R. Christensen and G. Knezek, "Measuring Teacher Attitudes, Competencies, and Pedagogical Practices in Support of Student Learning and Classroom Technology Integration," in *Second Handbook of Information Technology in Primary and Secondary Education*, J. Voogt, G. Knezek, R. Christensen, and K.-W. Lai, Eds. Cham: Springer International Publishing, 2018, pp. 1–19.

[10] J. Voogt, P. Fisser, N. Pareja Roblin, J. Tondeur, and J. van Braak, "Technological pedagogical content knowledge - A review of the literature," *J. Comput. Assist. Learn.*, vol. 29, no. 2, pp. 109–121, 2013, doi: 10.1111/j.1365-2729.2012.00487.x.

[11] M. Heitink, J. Voogt, L. Verplanken, J. Van Braak, and P. Fisser, "Teachers' professional reasoning about their pedagogical use of technology," *Comput. Educ.*, vol. 101, pp. 70–83, 2016, doi: 10.1016/j.compedu.2016.05.009.

[12] J. Harris and M. Phillips, "If there's TPACK, is there technological pedagogical reasoning and action?," *Res. Highlights Technol. Teach. Educ.*, no. 2004, pp. 13–22, 2018, [Online]. Available: https://www-learntechlib-org.cupdx.idm.oclc.org/p/182811/.

[13] M. Hofer and J. Harris, "Topics and Sequences in Experienced Teachers' Instructional Planning: Addressing a ~30-year Literature Gap," in *Proceedings of Society for Information Technology & Teacher Education International Conference 2019*, Mar. 2019, pp. 2443–2452,

[Online]. Available: https://www.learntechlib.org/p/207993.

[14] N. Janssen, M. Knoef, and A. W. Lazonder, “Technological and pedagogical support for pre-service teachers’ lesson planning,” *Technol. Pedagog. Educ.*, vol. 28, no. 1, pp. 115–128, 2019, doi: 10.1080/1475939X.2019.1569554.

[15] T. J. Kopcha, K. L. Neumann, A. Ottenbreit-Leftwich, and E. Pitman, “Process over product: the next evolution of our quest for technology integration,” *Educ. Technol. Res. Dev.*, vol. 68, no. 2, pp. 729–749, 2020, doi: 10.1007/s11423-020-09735-y.

[16] O. Trevisan, “Student-teachers’ Pedagogical Reasoning in Technological Pedagogical Content Knowledge Design Tasks a Cross- Country Multiple Case Study in Initial Teacher Education Institutions.”

[17] J. E. Hughes, Y. H. Cheah, Y. Shi, and K. H. Hsiao, “Preservice and inservice teachers’ pedagogical reasoning underlying their most-valued technology-supported instructional activities,” *J. Comput. Assist. Learn.*, vol. 36, no. 4, pp. 549–568, 2020, doi: 10.1111/jcal.12425.

[18] J. Holmberg, G. Fransson, and U. Fors, “Teachers’ pedagogical reasoning and reframing of practice in digital contexts,” *Int. J. Inf. Learn. Technol.*, vol. 35, no. 2, pp. 130–142, 2018, doi: 10.1108/IJILT-09-2017-0084.

[19] J. Loughran, “Pedagogical reasoning: the foundation of the professional knowledge of teaching,” *Teach. Teach. Theory Pract.*, vol. 25, no. 5, pp. 523–535, 2019, doi: 10.1080/13540602.2019.1633294.

[20] L. S. Shulman, “Knowledge and teaching: Foundations of the new reform,” *Harv. Educ. Rev.*, vol. 57, no. 1, pp. 1–22, 1987.

[21] A. Forkosh-Baruch, M. Phillips, and A. Smits, “Reconsidering teachers’ pedagogical reasoning and decision making for technology integration as an agenda for policy, practice and research,” *Educ. Technol. Res. Dev.*, vol. 69, no. 4, pp. 2209–2224, 2021, doi: 10.1007/s11423-021-09966-7.

[22] D. Farjon, A. Smits, and J. Voogt, “Technology integration of pre-service teachers explained by attitudes and beliefs, competency, access, and experience,” *Comput. Educ.*, vol. 130, no. November 2018, pp. 81–93, 2019, doi: 10.1016/j.compedu.2018.11.010.

[23] M. Heitink, J. Voogt, P. Fisser, L. Verplanken, and J. van Braak, “Eliciting teachers’ technological pedagogical knowledge,” *Australas. J. Educ. Technol.*, vol. 33, no. 3, pp. 96–109, 2017, doi: 10.14742/ajet.3505.

[24] M. Voet and B. De Wever, “Towards a differentiated and domain-specific view of educational technology: An exploratory study of history teachers’ technology use,” *Br. J. Educ. Technol.*, vol. 48, no. 6, pp. 1402–1413, 2017, doi: https://doi.org/10.1111/bjet.12493.

[25] M. Heitink, J. Voogt, L. Verplanken, J. Van Braak, and P. Fisser, “Teachers’ professional reasoning about their pedagogical use of technology,” *Comput. Educ.*, vol. 101, pp. 70–83, 2016, doi: 10.1016/j.compedu.2016.05.009.

[26] D. Stoilescu, “A Critical Examination of the Technological Pedagogical Content Knowledge Framework: Secondary School Mathematics Teachers Integrating Technology,” *J. Educ. Comput. Res.*, vol. 52, no. 4, pp. 514–547, 2015, doi: 10.1177/0735633115572285.

[27] C. Attard, N. Calder, K. Holmes, K. Larkin, and S. Trenholm, *Research in Mathematics Education in Australasia 2016–2019*. Springer Singapore, 2020.

[28] A. W. McCulloch, K. Hollebrands, H. Lee, T. Harrison, and A. Mutlu, “Factors that influence secondary mathematics teachers’ integration of technology in mathematics lessons,” *Comput. Educ.*, vol. 123, no. September 2017, pp. 26–40, 2018, doi: 10.1016/j.compedu.2018.04.008.

[29] M. B. Miles, A. M. Huberman, and J. Saldaña, *Qualitative data analysis: A methods sourcebook*, 3rd ed. 2014.

[30] D. P. Thomas and K. F. Hollebrands, *Focus in high school mathematics: Technology to support reasoning and sense making*. Reston, VA: National Council of Teacher of Mathematics, 2011.