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ORIGINAL PAPER

# Pre-service teachers' development of digital resource design capacity

Jana Trgalová[1] · Michal Tabach[2]

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**Abstract**

In the current digital age, (mathematics) teachers are provided with a profusion of digital resources. Consequently, research in mathematics education has focused on teachers' interactions with resources as the heart of their professional activity. The term Pedagogical Design Capacity (PDC) was introduced to designate teacher's ability to perceive affordances of resources and to make decisions about how to use them efficiently. PDC has been further conceptualized to define teacher design capacity (TDC) as including a goal or points of reference for the design, a set of design principles, and reflection-in-action. This definition is illustrated with case studies involving teachers' design of digital resources, yet it does not seem to consider the specificities of the latter. We therefore aim to further refine the concept of TDC by considering crucial components that designing technology-based tasks and their enactment in the classroom entail. We ask: What are the unique components of TDC specific to digital technology and resources? We elaborate a framework to suggest dimensions and components of mathematics teacher Digital Resource Design Capacity (DRDC) to emphasize the focus on design of digital resources. This framework is built on previous studies and on the concept of instrumental orchestration, and is refined taking into account findings from two case studies in France and Israel.

**Keywords** Mathematics teacher · Digital technology · Digital resource · Design capacity · Instrumental orchestration

## 1 Introduction

The profusion of available digital and non-digital resources, led researchers to focus on teachers' interactions with resources, considered as one of the main facets of their professional activity (Gueudet & Trouche, 2009; Remillard, 2005). Jones and Pepin (2016) point out that nowadays, teachers are considered as designers or as partners in the design of resources, rather than as their implementers. Also, use and re-use of existing resources are taken to be design-in-use. This echoes Brown's et al. (2009) view of teachers as designers. Hence, design as an integral part of teaching is gaining an increased interest in mathematics education research and among teacher educators. Yet, as noted by Beyer and Davis (2012), developing novice teachers' design capacity is challenging.

Pepin et al. (2017) further conceptualize and define teacher's pedagogical design capacity to include three main components: an orientation, a goal, or point/s of reference for the design; a set of design principles; and reflection-in-action [see Sect. 2.2 for details]. However, their definition does not seem to consider the specificities of the use of technology-based tasks. We therefore aim to refine the concept of pedagogical design capacity by suggesting components that we consider crucial when designing technology-based tasks and its enactment in the classroom. To emphasize the focus on design of digital resources, we introduce the concept of teacher Digital Resource Design Capacity (DRDC).

This paper is organized as follows. In Sect. 2 we present the theoretical framework and literature review. Drawing on these, we outline our suggested DRDC conceptualization (Sect. 3). In Sect. 4, we illustrate the use of DRDC framework for exploring the design capacity of prospective mathematics teachers engaged in collaborative design of digital resources within a teacher education course implemented respectively in France and in Israel. The subsequent revision of the framework is discussed in Sect. 5.

✉ Jana Trgalová
jana.trgalova@hepl.ch

Michal Tabach
TabachM@tauex.tau.ac.il

1 Haute École Pédagogique, Lausanne, Switzerland

2 Tel Aviv University, Tel Aviv, Israel

## 2 Theoretical background

We present an overview of existing conceptualizations and frameworks addressing teachers' interactions with resources (Sect. 2.1). We focus particularly on frameworks that deal with design capacity of teachers with the aim of highlighting dimensions and components deemed important by their authors. Pepin et al. (2017) suggest a conceptualization of *teacher design capacity* that we present in Sect. 2.2 as our purpose is to refine this framework to adapt it to digital resource design. To take account of specificities related to digital technology, we consider the concept of instrumental orchestration in Sect. 2.3.

### 2.1 Teachers' work with resources

Rezat et al. (2019) describe four approaches to conceptualizing teachers' work with resources among which two are closely linked to design capacity, namely *components of teacher–curriculum relationship* (Remillard, 2005) and *design capacity for enactment framework* (Brown et al., 2009). The latter was further elaborated into the notion of *pedagogical design capacity* (ibid.). Besides, Kim (in Rezat et al., 2019) suggests components of *teacher capacity for productive use of existing resources*. These approaches are described in what follows.

#### 2.1.1 Components of the teacher–curriculum relationship

Remillard (2005) assumes that "the teacher is an active designer of curriculum rather than merely a transmitter or implementer" (p. 214). She distinguishes between intended and enacted curriculum, the former referring to teachers' goals whereas the latter being what teachers implement in their classrooms. The author suggests four principal dimensions of the teacher–curriculum relationship: (a) the *teacher* with her resources, stances, and perspectives she brings to the participatory relationship with the curriculum, (b) the *curriculum* denoting both a written text and how this is perceived by the teacher, (c) the *participatory relationship between teacher and curriculum* consisting of interactions in which both entities are active participants, and (d) the *resulting intended and enacted curriculum*. The assumption behind the framework is that teachers interpret written curriculum in light of their knowledge, beliefs and experiences, which impacts curriculum that is subsequently enacted in classrooms. Implications drawn from the framework include the need for "substantial support in learning to use new curriculum materials" (p. 239), that can be offered to teachers via professional development opportunities.

#### 2.1.2 Design capacity for enactment framework and pedagogical design capacity

Assuming that "teaching is a process of design" and viewing "(curriculum) materials as resources to support such a process", Brown and Edelson (2003, p. 1) explore teacher–material relationship in terms of how the materials that teachers use influence their practice and how teachers interact with these materials, given their unique knowledge, skills, goals and beliefs. This teacher-material interplay is highlighted in "the design capacity for enactment framework" (ibid., p. 4). The framework comprises two main components: *curricular resources* that "are the representations of tasks, domain concepts and physical objects in the curriculum materials" (ibid.), and *teacher resources* including subject matter knowledge, pedagogical content knowledge and goals and beliefs that play "a key role in determining and constraining use of the curricular resources" (ibid., p. 5). Teacher's use of existing resources is characterized by the extent to which the resources are modified by the teacher, ranging from offloading when the teacher relies significantly on the material to support instruction, through adapting when the teacher adapts, deliberately or unintentionally, certain aspects of the material before implementing it, up to improvising when the teacher considers the material as a "seed" idea (ibid., p. 7) on which she builds own instructional design. Considering such teacher-resource relationship implies the importance of understanding teachers' *pedagogical design capacity* (PDC) that Brown et al. (2009) defined as teacher's "skill in perceiving the affordances of the materials and making decisions about how to use them to craft instructional episodes that achieve her goals" (p. 29). Brown and Edelson (2003) suggest several directions in terms of teachers' professional development, including supporting teachers "in exploring which resources to use and how to use them" (p. 6) that aims at helping teachers align their instructional goals with affordances of the resource and make the necessary adaptations of the resource to achieve this alignment. Thus, teacher preparation and professional development "might explicitly target the design skills required for effective use of instructional materials" (ibid.). Note that besides the "capacity to perceive underlying curricular goals" that the authors link with PDC, no other design skills are mentioned, leading other scholars to refine the PDC (e.g., Pepin et al., 2017, see Sect. 2.2).

#### 2.1.3 Teacher capacity for productive use of existing resources

Extending Brown's notion of PDC and building on Remillard's idea of participatory relationship between teachers and resources, Kim (in Rezat et al., 2019) explores the productivity of teachers using existing resources. The author considers this productivity depending on the opportunity for students to learn during the lessons. Five specific aspects of teacher capacity for productive resource use are mentioned: (1) identifying the mathematics at stake in the resource and evaluating the extent to which the resource supports students' learning of these mathematics; (2) steering instruction toward the mathematics at stake; (3) recognizing affordances and constraints of the resource in use; (4) using affordances; and (5) modifying the resource to overcome constraints or improve lessons. According to the author, these aspects might be considered in teacher education and professional development to develop teachers' capacity for productive resource use.

From this brief presentation of frameworks approaching design capacity of teachers, we notice the following gaps emerging. First, some frameworks mention specific design skills or design principles as a component of the design capacity, nevertheless these skills or principles are not precisely defined. Second, we can infer several components of the design capacity from these frameworks, namely:

- To decide which resources to use and how to use them (Brown & Edelson, 2003)
- To interpret curriculum and to align the design to it (Remillard, 2005)
- To identify mathematics at stake in the resource and the extent to which the resource may be conducive to students' learning (Kim, in Rezat et al., 2019)
- To explicate and justify design decisions (Remillard, 2005)
- To recognize and use affordances in a resource and to modify the resource to overcome constraints (Kim, in Rezat et al., 2019).

Finally, these frameworks are not specific to digital resources. Pepin et al. (2017) suggest further conceptualization of Brown's notion of pedagogical design capacity to understand teachers' interactions with digital curriculum resources. We present next their framework of teacher design capacity.

### 2.2 Teacher design capacity

Pepin et al. (2013) consider teaching as design that encompasses both the practice of designing for teaching (i.e., design before enactment) and "design-in-use" (i.e., during the resources enactment). Based on Brown and Edelson's (2003) definition of pedagogical design capacity (PDC), Pepin et al. (2017) further conceptualize it and define teacher design capacity (TDC), including three main components:

- "An orientation, a goal, or point/s of reference for the design" (p. 802), comprising knowledge of the classroom context (what do students know, their misconceptions), understanding of the curriculum guidelines and the learning trajectory related to a specific topic, and the ability to position the design in the short (lesson cycle) and the long term (across grades),
- "A set of design principles" that must be both robust, i.e. "evidence-informed […] and supported by justification for their choices", and flexible enough "to adapt to new challenges and contexts" (ibid.),
- ""Reflection-in-action" type of implicit understandings and realizations" (ibid.) enabling the teacher to adapt her actions during instruction.

The first component echoes Remillard's (2005) idea of understanding the curriculum and aligning resource design to it, and adds a consideration of students' prior knowledge and learning trajectory when designing a resource. The second component does not provide any precise design principles; the teachers should be able to make them explicit and justify their choices, which is also aligned with Remillard's point of view. The third component assumes teachers' ability to make ad hoc decisions during the resource enactment.

Although the authors illustrate their conceptualization of TDC in two case studies involving teachers' designs of digital resources, none of the three components addresses the specificity of digital technology or resources. To fill this gap, we consider the notion of instrumental orchestration.

### 2.3 Instrumental orchestration

The notion of *instrumental orchestration* was introduced by Trouche (2004), to describe teachers' practice aimed at supporting their students while working on mathematical problems in the presence of technological tools. Trouche (2004) introduced "the term *instrumental orchestration* to point out the necessity of *external steering* of students' instrumental genesis" (p. 296, emphasis in the original).

Instrumental orchestration is defined by four components: a set of *individuals*; a set of *objectives* (related to the achievement of a type of task or the arrangement of a work environment); a *didactic configuration* (a general structure for the plan of action); a *set of exploitations* of this configuration (Guin et al., 2005, p. 208).

While the didactic configuration refers to the arrangement of artefacts in the classroom, the exploitation mode includes "decisions on the way a task is introduced and worked through, on the possible roles of the artefacts to be played, and on the schemes and techniques to be developed and established by the students" (Drijvers et al., 2010, p. 215). The teacher designs parts of her instrumental orchestration in advance, while other parts may emerge during a lesson, as “didactic performance” (Drijvers et al., 2010) or “reflection-in-action” (Pepin et al., 2017).

Drijvers and colleagues (Drijvers et al., 2010, 2013), have further developed the notion of instrumental orchestration by providing typology and an operational definition for specific instrumental orchestration types. Recently, Drijvers et al. suggested that “the notion of instrumental orchestration might be a very suitable starting point for teachers’ professional development” (2020, p. 1466), specifically for designing a chain of orchestrations to their class.

From the above considerations, we retain the teacher design capacity (TDC) as an important facet of teachers’ professional competency. As we have shown, although several frameworks are suggested to define skills encompassed by the TDC, their description remains at a rather general level. Moreover, none is specific to the design of a lesson incorporating digital resources. We therefore aim at elaborating further components of the TDC in the context of technology-supported design. Our elaboration is guided by the question: What are the unique components of the teacher design capacity specific to digital technology and resources?

## 3 Mathematics teacher digital resource design capacity

We suggest components of what we propose to call teacher *digital resource design capacity* (DRDC) to emphasize the specificity of design when digital technology is mobilized. To do so, we use the teacher design capacity conceptualization suggested by Pepin et al. (2017), combined with the notion of instrumental orchestration.

Following Pepin et al. (2017), digital resource design includes **designing for teaching** (before enactment) and **design-in-use** (during enactment), to which we add **redesign**, i.e., after enactment, reconsidering initial design choices in light of the actual lesson implementation. Next, we propose components for each of the three dimensions of the DRDC (in bold above) with a brief rationale.

**Design for Teaching** (DefT). Three skills are particularly important when designing a digital resource:

- *(DefT1) To choose relevant digital technology* (DT). Digital technology should be relevant with respect to the learning goal (DefT1-a), and to the context of the classroom, in particular students’ knowledge, both mathematical and instrumental, and misconceptions (DefT1-b). These components draw on the goal/orientation component of the TDC (Pepin et al., 2017).
- *(DefT2) To design tasks mobilizing the chosen DT* that
  - contribute to the learning goal achievement (Pepin et al., 2017; Kim in Rezat et al., 2019) (DefT2-a);
  - build on previously acquired mathematical and instrumental knowledge (Pepin et al., 2017) (DefT2-b);
  - align with curriculum (Pepin et al., 2017; Remillard, 2005) (DefT2-c);
  - present an added value using DT (DefT2-d). This component is related to recognizing and making use of digital technology affordances and reflects the specificity of digital resource design.

The DefT2 component includes a set of design principles from the TDC and is closely related to the orientation/goal for the design.

- *(DefT3) To plan classroom enactment of the tasks*. We refine this component reflecting a set of design principles in TDC (Pepin et al., 2017) by drawing on the notion of instrumental orchestration. This component comprises steering students’ mathematical activities with DT, which necessitates teacher’s accompanying students’ instrumental geneses. The following skills are therefore required:
  - to organize phases of the task enactment (launching the task, individual/group work, whole class discussion…) (DefT3-a);
  - to plan didactical configuration and exploitation mode (DefT3-b);
  - to plan teacher’s interventions in response to anticipated students’ strategies and difficulties (DefT3-c);
  - to plan the institutionalization articulating mathematical and instrumental knowledge (DefT3-d).

**Design-in-Use** (DeiU) includes teacher’s on-the-spot interventions, which aligns with didactic performance of the instrumental orchestration (Drijvers et al., 2010) and echoes reflection-in-action in TDC. It thus includes, but is not limited to, the abilities to decide what question to pose now, how to do justice to (or to set aside) student input, how to deal with unexpected aspect of the mathematical task or the technological tool, or other emerging goals.

**ReDesign** (ReDe) of the digital resource after enactment relies on the assessment of the task design in light of what happened in class. It includes the abilities to identify what went well and what can be improved (ReDe-a); and to suggest modifications of the resource (ReDe-b).

# 4 Prospective teachers' development of DRDC

We have used the theory based DRDC framework (Sect. 3) to analyze digital resources designed by teams of prospective secondary school mathematics teachers within their teacher education program in order to assess the development of their DRDC. In this section, we present a teacher education course aiming at supporting the development of pre-service teachers' design capacity implemented in France and in Israel (Sect. 4.1), and highlight components of DRDC evidenced in the resources they designed (Sect. 4.2). Findings from the resource analyses led us to revise the DRDC framework, as discussed in Sect. 5.

## 4.1 Teacher education course aiming at supporting DRDC development

The course was implemented at Claude Bernard University in Lyon, France and at Tel-Aviv University in Israel. The implementation of the course in two different countries aims at testing the framework in two different cultural and institutional contexts.

### 4.1.1 Context

In Lyon, two courses focusing on the use of digital technology in mathematics teaching and learning are offered. The first-year course of the Master program for pre-service secondary school mathematics teachers aims at exploring technology potentialities (technology as object of study). The second-year course of the program focuses on integration of digital technology in the pre-service teachers' practices. Thus, the participating students are supposed to master digital technology used in the second-year course well enough to be able to engage in reflecting on educational usages of the technology (technology as a tool for teaching and learning mathematics). The students enrolled in the course are half-time mathematics teachers in a (lower or upper) secondary school and half-time Master students. The course duration is 15 h, organized in seven 2 to 3-h sessions.

The teacher education program at Tel-Aviv University also aims at preparing future teachers to be familiar with the use of digital technology, first as mathematics problem solvers in a digital environment, and then as teachers who are expected to support their students to become skillful problem solvers in digital environments. Each course participant attends a specific high school for one day a week, working with the same classrooms throughout the year. The profile of the Israeli participants is thus similar to their French peers. The course duration is 26 h, organized in 13 2-h meetings.

### 4.1.2 The course

In the first part of the course, the instructors proposed to participants various mathematical tasks allowing them to explore mathematics topics (arithmetic, algebra, functions, geometry, statistics, probability, series) with digital technology, including dynamic geometry, spreadsheet, Scratch and Python—tools that are recommended by the secondary school mathematics curricula. Student-teachers' teams were invited to solve the tasks and discuss how the digital tools they chose contribute to teaching and learning mathematics at stake in the tasks. This part of the course was designed to foster the development of the skills needed for designing digital resources, namely *to identify a learning goal* (DefT1-a), *to choose digital technology relevant with respect to this learning goal* (DEfT2-a) and *to analyze added value of digital technology* (DefT2-d). The second part of the course was designed to engage the participants, in teams of 1–4 members, in the design of a digital resource consisting of: (1) a task mobilizing a digital tool that, in Lyon, at least some of the team members would enact in their classrooms,[1] (2) a rationale explaining the design choices and arguing the contribution of the digital tool to the achievement of the learning goal, and (3) classroom enactment plan. The design of the resources was monitored by the instructors who scaffolded the design process (Becuwe et al., 2016) by various actions. First, they provided support to the design teams in the form of a resource template (see Appendix 1) that guided the teams towards defining mathematical topic, learning goal and school level addressed by the resource, choosing a digital tool, designing the technology-enriched task, performing a priori analysis of the task, and suggesting a planned classroom enactment. Second, to facilitate the resource design, the instructors introduced theoretical considerations when appropriate, including:

- Old/new dialectics (Assude & Gélis, 2002): when integrating a digital tool, teachers need to pay attention to students' mathematical and instrumental prerequisites

[1] In Tel Aviv, the enactment of the designed resources was not possible.

**Table 1** Structure of the course aiming at the development of DRDC

| | Content | Teacher education activities | DRDC components |
|---|---|---|---|
| **Part 1**<br>Sessions 1–3 (Lyon)<br>Meetings 1–9 (Tel Aviv) | Solution and a priori analysis of tasks proposed by the instructors, with or without suggestions of DT to be used | Using exemplary materials | **Design for teaching**<br>To identify the mathematics learning goal (DefT1-a)<br>To choose relevant DT (DefT1)<br>To analyze added value of the DT (DefT2-d) |
| **Part 2**<br>Meeting 10 (Tel Aviv) | Familiarization with the evaluation grid | Using the evaluation grid to analyze existing resources | **Design for teaching** (DefT1, DefT2) |
| **Part 2**<br>Sessions 4–5 (Lyon)<br>Meeting 11 (Tel Aviv) | Digital resource design | Designing a digital resource | **Design for teaching** (DefT1, DefT2, DefT3) |
| **Part 2**<br>Session 6 (Lyon)<br>Meeting 12 (Tel Aviv) | Peer evaluation of the resource design | Evaluating designed material | Analysis and evaluation of the **design for teaching** |
| **Part 2**<br>Session 7 (Lyon) | Classroom enactment report | Sharing experiences of the conducted design process | **Redesign**<br>To identify what went well and what did not (ReDe-a)<br>To identify what can be improved and suggest modifications of the tasks (ReDe-b) |

so that no new mathematical knowledge is introduced with a new tool. Introducing this theoretical consideration aims at supporting participants' reflection about the *articulation of students' mathematical and instrumental knowledge* (DefT1-b) in the design phase.

- SAMR framework[2] (Hamilton et al., 2016; Puentedura, 2006): a conceptual tool to *reflect on the added value of the digital tool* (DefT2-d) (Trgalová, 2022).
- Instrumental orchestration (Trouche, 2004): the ways of accompanying students' exploitation of the digital tool, and hence aimed at supporting student-teachers *plan the enactment of the designed task* (DefT3).

Finally, the instructors provided the design teams with feedback on intermediate versions of their resources.

During the resource design, the design teams offered critical feedback to their peers and redesigned their resources considering peers' critics and suggestions. Referring to Huizinga et al.'s (2015) activities to favor the design capacity development, the teams were engaged in evaluating designed materials. The evaluation was organized in the following phases: (1) familiarizing the participants with the evaluation grid (only in Tel Aviv), (2) each design team evaluated the resource of another team, (3) the pairs of teams exchanged about their mutual evaluations, explained their appreciations and offered suggestions for the resource improvement, and (4) the design teams redesigned their resources taking into account both the peer evaluation and the instructors' feedback on the intermediate resource versions. The instructors supported the evaluation of the resources by providing the design teams with an evaluation grid (see Appendix 2) comprising:

- Four evaluation criteria: description of the instrumented task, relevance of the digital tools mobilized in the task (DefT1, DefT2), a priori analysis of the learners' activity, and description of the teacher's role (DefT3),
- Overall appreciation of the resource,
- Suggested improvements.

In Lyon, the course was concluded by resource presentations and reports from the experiences of their classroom enactments by members of the design teams. The design teams were asked to highlight strengths and weaknesses of their designs (ReDe-a), to account for the classroom enactments by emphasizing the students' learning and the role of the digital tool and to suggest improvements of their resources (ReDe-b). Reports and sharing experiences aimed at supporting the participants in *assessing the resource design based on* a posteriori *analysis of classroom implementations* (ReDe). Table 1 presents an overview of the structure of the course.

[2] The acronym SAMR stands for Substitution—technology acts as a direct tool substitute, with no functional change; Augmentation—technology acts as a direct tool substitute, with functional improvement; Modification—technology allows for significant task redesign; and Redefinition—technology allows for the creation of new tasks, previously inconceivable.

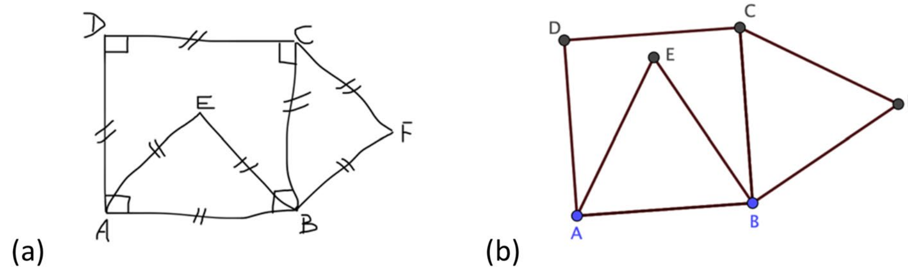


**Fig. 1** The figure (**a**) given in the task (excerpt from the resource), (**b**) created with GeoGebra

## 4.2 Analysis of the designed digital resources

To illustrate the use of the framework for studying student-teachers' design capacity, we analyze two resources produced by two design teams, one in Lyon (Sect. 4.2.1) and one in Tel Aviv (Sect. 4.2.2). We start each case by describing the mathematical task designed, followed by the analysis of the corresponding resource. The identified components of the DRDC are highlighted in italics. A summary of the findings ends this section (Sect. 4.2.3).

### 4.2.1 French case

For our analysis, we chose the resource designed by three student-teachers who document particularly well their design process, highlighting clearly what had been modified following peer evaluation. Moreover, all the three student-teachers implemented the designed task in their classrooms and their reports highlight modifications done in the redesign phase building on the report of the teammates, thus providing information about the redesign of the resource.

The task the team designed for their Grade 6 students (11–12-years) is the following: ABCD is a square, ABE and BCF are two equilateral triangles (Fig. 1). The students are asked to conjecture the relationship between points D, E and F (they are aligned). The task implementation is planned in several phases: (1) construction of the corresponding figure on paper with traditional geometry instruments (ruler, compass, set square) and conjecture about the relationship between D, E and F; (2) whole-class discussion to share and debate the conjectures; (3) construction of the figure with GeoGebra and verification of the conjectures; (4) synthesis of the activity.

The a priori analysis of the task allows to understand the authors' intentions: the students' constructions on paper would not be precise enough, which would lead to contradictory conjectures—some students would suppose the points are aligned, others would not. This contradiction would be highlighted in the whole-class discussion. GeoGebra would then be used to produce precise drawings, leading to a (valid) conjecture that, what is more, could be verified for different configurations by dragging the free points.

In their intermediate version of the resource, the design team defines the *learning goal* (DefT1-a) of the task as to "draw a robust figure" (Fig. 2).

The team designed the task to introduce GeoGebra to students who are not familiar with it. The instructor's feedback invited the team to revise their learning goal to address a mathematical topic with the use of digital technology, rather than to focus on instrumental knowledge. The peer evaluation highlights the potential of the task to introduce the notion of conjecture. Both suggestions led the design team to revise and refine the identity card of their resource, highlighting the evolution of the learning goal from considering instrumental knowledge only to *articulating mathematical and instrumental knowledge* (DefT1-b): in the final version of the resource, the task aims at leading students to discover the notion of conjecture (mathematical goal) through the use of GeoGebra (Fig. 3), drawing on the robust construction paradigm (Laborde, 2005). Moreover, the team is aware that in Grade 6, students are progressively introduced to deductive geometry by focusing on geometric properties of figures and that the notion of proof is not dealt with explicitly before Grade 7 or 8 (DefT2-c).

This analysis highlights the predominance of instrumental aspects over the mathematical ones when designing technology-based tasks by the teams (similar tendency was observed in several other designs). To stress the importance of considering digital technology as a tool for teaching mathematics, we add a new component to the Design for Teaching dimension: *to set up a mathematical learning goal* (see Sect. 5).

To justify the choice of GeoGebra, the design team wrote:

> The software only makes it possible to reinforce the intuition of the pupils, or even simply to obtain a pre-

| | |
|---|---|
| Math topic | Geometry |
| School level | |
| Learning goal | Draw a robust figure |
| Digital tool | Geogebra |

**Fig. 2** Excerpt from the intermediate version of the resource showing its identity card

**Fig. 3** Excerpt from the final version of the resource identity card. In italics, modifications following peer evaluation

| | |
|---|---|
| Math topic | Geometry |
| School level | Grade 6 |
| Learning goal | *Bring out the notion of robustness of a dynamic figure* |
| Indirect learning goal | *Discover the notion of conjecture, of proof that is not in the Grade 6 curriculum* |
| Digital tool | Geogebra |
| Professional problem | *The activity makes it possible to test classroom management of an instrumented task (geogebra). Reflect on the versatility of a mathematical task (the task involves several concepts: notion of robustness, of conjecture / proof…) Experimentally verify the student conjectures. Finally, the paper construction differs from geogebra, which leads to consider properties of the figures and their use in construction.* |

> cise drawing (be careful, when institutionalizing insist on the fact that geogebra only allows to conjecture, not to prove) (...)
> Observe whether the alignment is true for any length of the side of the square: robustness of the figure. (Excerpt from the resource)

GeoGebra is thus chosen for its affordances (DefT2-d) to enable precise drawings facilitating conjecturing geometric properties that are inferred from the invariants the students observe while dragging free points in robust constructions. Moreover, the student-teachers note that

> In Grade 6, precision in geometry is often lacking: measure a length, draw precisely a segment, set square misplaced to draw a right angle, report length with a compass (Excerpt from the resource)

A recourse to Geogebra is thus also motivated by the desire to address explicitly this difficulty with the students (DefT1-b). We consider the skill *to identify and use affordances of DT* both *to allow the achievement of the learning goal* (DefT1-a) and *to address students' difficulties or misconceptions* (DefT1-b) as crucial when designing an instrumented task, therefore, we emphasize it by adding it more explicitly in the DRDC framework (see Sect. 5).

Among the choices made to design the task (Fig. 1), student–teachers highlight and justify the following one:

- in the task statement: a freehand drawing of the figure is provided with the aim to prevent the students from verifying the alignment of the points; the length of the side of the square is not given to let the possibility to test the robustness of the construction,
- regarding GeoGebra tools: hide axes and grid to avoid the students to use them when constructing a square; prevent students from using 'regular polygon' tool since the aim is to foster the use of geometric properties to construct a square.

Another added value of GeoGebra (DefT2-d) resides, according to the design team, in the difference in construction procedures compared to paper–pencil environment, "which leads to reflection on properties of figures and their use when constructing them" (excerpt from the resource). Referring to the SAMR levels of technology integration, the intended use of GeoGebra is considered as augmentation since "the software in Grade 6 allows a simple augmentation of the precision", but also as modification, since "the figure, via its robustness, allows representing a huge number of cases" (excerpts from the resource). These excerpts show that the team analyzed differences between techniques within the digital environment and the traditional ones enabling them to identify the contribution of GeoGebra to achieve the learning goal in the designed task, evidencing DefT2-a and DefT2-d.

The team plans the resource enactment during two lessons. The first lesson is held in an ordinary classroom. Students are asked to individually construct the figure (Fig. 1) with ruler and compass, which leads them to first think about the order of the construction and second, to observe the relationship between the points D, E and F. The whole-class discussion should then make the students aware of the discordant answers due to their imprecise drawings, which would motivate the use of GeoGebra. This choice highlights an interesting design principle that drawbacks of traditional tools motivate the use of digital technology (DefT2-d).

The second lesson is held in a computer lab where there are not enough computers allowing students to work individually, therefore they work in pairs. Several phases are highlighted in the lesson plan demonstrating the student-teachers' skill to *organize phases of the task enactment* (DefT3-a, b) (note that the labels of instrumental orchestrations mentioned below referring to Drijvers et al. (2013) come from the researchers based on detailed descriptions of didactic configurations and exploitation modes provided in the resource):

- launching the activity with a whole class technical demo orchestration aiming at showing how to hide axes and grid and explaining why the use of the 'regular polygon' tool is forbidden;
- students constructing the figure with individual orchestrations such as technical demo, guide-and-explain or discuss-the-screen;
- whole-class discussion aiming at validating the students' constructions with the whole-class discuss-the-screen orchestration (teacher's screen being projected), followed by the teacher constructing the figure and the students who have not succeeded their construction constructing the figure again at the same time;
- students formulating conjectures with the whole-class discuss-the-screen orchestration;
- institutionalizing with the whole-class board-instruction orchestration:

  - the notion of robust figure in GeoGebra;
  - the notion of conjecture;
  - the role of GeoGebra in solving a task in support of an idea, a hypothesis: "the software allows avoiding errors due to imprecise drawings and to see that the points keep aligned whatever the length is" (excerpt from the resource);
  - the notion of proof: "later this year, we'll know how to prove that these points are really aligned with the help of angles" (excerpt from the resource).

The above-mentioned institutionalization shows attention paid to articulating the mathematical and the instrumental knowledge (DefT3-d).

The lesson plan and the analysis of the teacher's role present in the resource, evidence student-teachers' reflections about setting up adequate instrumental orchestrations, i.e., *planning didactic configurations and exploitation modes* (DefT3-b). Furthermore, they anticipate students' difficulties and foresee interventions, thus *planning their didactic performance* (DefT3-c), as can be seen from the following excerpt:

> Hint in case of getting stuck:
>
> (i) hint in the form of a question (when stuck with the use of the compass) how can a length be reported in geometry on paper? (…) With what tool? (…) Which Geogebra tool can be used as a compass? = > construction of a circle center-point
> (ii) for groups with severe difficulties: there exists 'regular polygon' tool! it is enough to enter the correct number of sides… (excerpt from the resource)

The resource was enacted in the classes of all three team members, enabling us to look for instances of Design-in-Use (DeiU) and ReDesign (ReDe) components. Yael[3] reports several deviations compared to the lesson plan, evidencing DeiU (e.g., omitting a whole-class discussion related to the ruler and compass constructions, or validating the alignment of points before the instrumented activity). He also reports (unforeseen) students' difficulties with constructing a robust figure leading him to permit the use of 'regular polygon' tool. When institutionalizing, he dictated the following sentence: "a robust figure in Geogebra is a figure that does not change when one of its points are dragged" (excerpt from Yael's report). One of his students reacted that this was not true as the figure could get larger or smaller. Yael completed then "it can get bigger or smaller, but a square remains a square, a triangle remains a triangle", confessing that "it was clumsy, as by dragging a right-angled triangle can become isosceles while remaining a triangle" (Excerpt from Yael's report). The report shows a complexity of classroom management despite following a well-designed lesson plan, due to time constraints ("wanting to go too fast") and facing students' mainly technical difficulties. Teacher's adaptations to unforeseen events were not always appropriate ("it was clumsy…").

Ann's enactment followed the lesson plan. She reported anticipated students' difficulties for which interventions had been planned during the design. The robust figure was institutionalized as follows:

> In Geogebra, we have seen that a figure is called robust when it keeps its characteristics (alignment, parallelism, perpendicularity) following a modification (enlargement, reduction, rotation). In our case, after modification, a square remains a square, an equilateral triangle keeps its features, the points D, E and F remain aligned (excerpt from Ann's report).

Leon enacted the resource later than his teammates and could read their reports. The reported "clumsiness" of Yael's definition of a robust figure led Leon to elaborate the following one:

> A figure is called robust if its properties (alignment of points, relations between lengths, parallelism, and

[3] The names of the student-teachers are nicknames.

relations between angles) are preserved when vertices of the figure are dragged. (Excerpt from Leon's report)

From these reports, it comes out that the teamwork can be beneficial during the design-for-teaching phase and also when sharing experiences from classroom enactment. Indeed, the student-teachers (namely Leon) demonstrated their ability to draw on limitations highlighted in teammates' reports to improve the resource and their own enactment, evidencing ReDe-a and ReDe-b components.

#### 4.2.2 Israel case

For our analysis, we chose a resource that was designed by a team of two student–teachers, as they provided detailed rationale for their design. Next, we describe the designed resource followed by an analysis of the design rationale by referring to Sect. 3.

The task was designed for a 90 min lesson with 11th Grade students about the meeting point of the medians in a triangle theorem: "Any two medians in a triangle divide each other into two segments, so that the segment near the vertex is twice as long as the other part", and as a conclusion "the three medians in a triangle have one meeting point". The theorem was new to the students. The team articulated three learning goals: to raise a conjecture about the medians meeting point; to prove the conjecture; to use the theorem's implications in exercises.

The a priori analysis of the task allows us to understand the team's intentions. They describe the learning goals in terms of the mathematical knowledge to be learned, in accordance with the official syllabus requirements (DefT2-c). According to the three learning goals, the team chose to implement the lesson by using three different digital technologies. As we illustrate next, each digital technology was relevant to the learning goals set in each phase (DefT1-a).

For the conjecturing goal, GeoGebra was selected so that the students would build the mathematical situation (a triangle and its three medians) and use length measurements and the dragging mode in order to raise a conjecture. As research shows, one of the powers of dynamic geometry environments is allowing for conjecturing (e.g., Arzarello et al., 2002). To clarify, inviting 11th Grade students to conjecture is unfortunately not a common practice in Israel. The design further invites the students to reason why the conjecture they raised holds.

For the proof of the theorem (second goal), the team thought that the proof is complex and includes several steps. Hence, the chosen digital technology was a powerpoint presentation. An accompanying powerpoint presentation was set up by the team so that the teacher will be able to use it during the whole-class discussion phase to support both her and the students. This design choice implies not only *recognizing and making use of affordances* of the technology (DefT2-d), but also points at DefT3-b—*plan didactical configuration and exploitation mode* with respect to DefT3-c—*teacher's interventions in response to anticipated students' strategies and difficulties.* Note that the team points out the need to support the teacher during this phase. Our frame, as was articulated in Sect. 3, does not explicitly capture this critical point.

For the implementing the theorem in exercises (third goal), the team chose a third digital technology, a digital platform on which students were given a set of questions: the platform allowed, on the one hand, dynamic interactions with the given figures and, on the other hand, check their solutions. By doing so, the design team utilized two characteristics of this particular resource—first, the task itself is presented dynamically, and second, there is immediate feedback regarding the correctness of students' input. These two are features aiming at supporting the learner's activity. From the point of view of the teacher, she can have the summary of all the students' performances on these tasks, hence allowing her to further plan her teaching based on students' performances.

So, we can see that indeed the team's choices for each of the three digital technologies was aimed at providing an answer to the specific needs of the different lesson parts, in accordance with DefT2.

The team's plan was geared toward DefT3—*classroom enactment of the tasks*. They consider the first conjecturing phase in their designed lesson to be important, as it calls for their students to act as independent enquirers (part of planning the exploitation mode, DefT3-b). The presence of GeoGebra was crucial for achieving this aim. To allow students to be successful in their inquiry, the team considered first the needed background mathematical knowledge, but also technological knowledge for acting with GeoGebra (DefT1-b and DefT2-b):

> The students need to be familiar with geometrical knowledge prior to this theorem - properties of triangles, properties of four-side-polygons (part of the proof demands mastering properties of a parallelogram), and means section (central for the theorem's proof). Likewise, they need to master ratios, as the theorem speaks about the ratio between the two parts of the median the intersection point divides. Finally, the students need a basic knowledge on how to operate the computer and Geogebra. (excerpt from the resource)

To help students with the technical aspects, the team provided detailed instructions for the construction. However, during the peer evaluation phase, the other team commented on the "density" of the designed lesson and suggested providing students with "partially constructed" GeoGebra applet.

This suggestion was accepted by the designers, as they saw the importance of letting students focus on conjecturing and coming up with some reasoning for how to prove the ratio by which the medians are divided into by the intersection point. We see this as part of DefT2-d, namely *recognizing and making use of affordances of the digital technology* for fostering the mathematical goal.

As we reported above, the team planed for the enactment of the task (DefT3), *by organizing phases of task enactment* (DefT3-a), for example by anticipating that the actual proof of the theorem would be quite complex. Here they harnessed the use of a pre-designed powerpoint presentation as a resource that will allow them to break the proof into sub-steps and help keep the focus of the students during the whole-class institutionalization phase (DefT3-c&d). On the other hand, this pre-planned proof might be a sign of the teams' belief that the reasoning students will come up with to prove the conjecture might not be solid enough to build on it the actual proof.

So, the format provided to the teams led them also to consider and plan the actual enactment in class (DefT3). The planned lesson alternated between different working formats: a short opening in a whole-class mode, followed by individual students work with GeoGebra to construct the situation, conjecture and reason, then a whole-class institutionalization by proving of the theorem, then again students' work on applications of the theorem to solve some exercises. Within each phase, the team articulated the didactical configuration and the exploitation mode (DefT-b), and the expected roles of the teacher and students (DefT3-c).

#### 4.2.3 Summary of the two cases

While the resources developed by the French and Israeli teams described and analyzed above differ considerably in the mathematical content, learning goals, chosen technology (both mathematics-specific, and general in the Israeli case), lessons configuration and more, the framework of DRDC articulated in Sect. 3 allowed us to analyze them and highlight components of the team members' design capacity. Note that all components were identified in the two cases. Yet, while analyzing the cases, we stumbled upon issues that are central to digital resources design capacity, but are not present in our framework. Hence, in the discussion section (Sect. 5) we revised the framework to include those components.

## 5 Discussion

Considering the importance of viewing teachers as designers of their instruction, in this paper, we focused on teachers' professional competencies related to resource design. An abundant literature exists elaborating on concepts of pedagogical or teacher design capacity. However, rare are studies highlighting specificities of design of digital resources. Our paper therefore aimed at contributing to this research by suggesting a framework defining teacher digital resource design capacity (DRDC). Based on a literature review and theoretical considerations, we have identified several design capacity components, some of which are specific to digital resources, that we articulated into the DRDC framework according to three dimensions, namely design for teaching (DefT), design in use (DeiU) and redesign (ReDe).

We used the framework to analyze resources designed by teams of pre-service secondary school mathematics teachers during a teacher education course. The analyses reported in the paper show that the resources evidence most of the components of the DRDC. However, they also highlight several components that seem important and that were not captured in our framework. Hence, we suggest a revision of the framework by adding the following two components emerged from our analysis, namely:

- The *ability to set up a mathematical goal* for a digital resource appears crucial when the chosen digital technology ought to be considered as a tool to support mathematics teaching and learning.
- The design teams expressed the need to support teacher's interventions by *providing all necessary material* that would facilitate the teacher's enactment of the resource in the classroom. This component has been added to DefT3.

Moreover, we consider the abilities *to identify and use affordances of digital technology* both *to allow the achievement of the learning goal* (DefT1-a) and *to address students' difficulties or misconceptions* (DefT1-b) as key when designing an instrumented task. We therefore emphasize them by an explicit formulation regarding the added value of technology. Table 2 shows the revised DRDC framework.

Our analyses point out several aspects of the course promoting the development of DRDC. First, the course, implemented in France and in Israel, was organized in a way to promote participants' learning from and with their peers through collaborative resource design and peer evaluation. This choice turned out to be highly relevant, resulting in deeper design enriched by the peer's feedback, which echoes other studies about teachers' learning through collaboration (e. g., Binkhorst et al., 2022; Borko & Potari, 2020; Jaworski et al., 2017). Second, the instructors' role appeared crucial to facilitate all phases of the teams' design. The instructors' role was threefold, echoing the roles of facilitators accompanying teacher design teams identified by Becuwe et al. (2016), namely *providing logistic support*, *scaffolding the*

**Table 2** Revised DRDC framework

| | |
|---|---|
| **Design for teaching (DefT)**<br>(before enactment) | **(DefT0) To set up a mathematical learning goal**<br>(a) Choose a mathematical content that the task will be aiming at.<br>(b) Analyze how the mathematical goal is aligned with the curriculum. |
| | **(DefT1) To choose relevant digital technology (DT)**<br>(a) Identify affordances of DT allowing to achieve the learning goal.<br>(b) Identify affordances of DT allowing to address students' difficulties or misconceptions. |
| | **(DefT2) To design tasks mobilizing the chosen DT and justify the design choices**<br>(a) Analyze in what way the tasks contribute to the achievement of the learning goal.<br>(b) Identify previously acquired (math and instrumental) knowledge necessary to engage in the tasks.<br>(c) Highlight affordances of the DT that allow for a different approach to achieving the targeted learning (added value of DT). |
| | **(DefT3) To plan classroom enactment of the tasks:**<br>(a) Organize phases of the task enactment (introduction, individual /group work, whole class discussion…).<br>(b) Plan didactic configuration and exploitation mode.<br>(c) Plan teacher's interventions in response to anticipated students' strategies and difficulties (planned didactic performance).<br>(d) Plan the institutionalization articulating math and instrumental knowledge.<br>(e) Provide material to support the teacher's interventions (presentations, student worksheets…). |
| **Design-in-use (DeiU)**<br>(during enactment) | **(DeiU) On-the-spot teacher's actions and decisions (improvised didactic performance) about:**<br>what question to pose now,<br>how to do justice to (or to set aside) any particular student input,<br>how to deal with an unexpected aspect of the mathematical task or the technological tool, or other emerging goals |
| **ReDesign (ReDe)**<br>(after enactment) | **To assess the task design based on an a posteriori analysis:**<br>(a) Identify what went well and what did not.<br>(b) Identify what can be improved and suggest modifications of the tasks. |

*design process* and *monitoring the design*. The *logistic support* consisted in coordinating and organizing design teams (both for designing resources and peer evaluating the designs), scaffolding the design process consisted in providing templates for the design and evaluation of the resources (see Appendix 1 and 2), as well as introducing theoretical considerations when appropriate to help reflecting on and justifying design choices. *Monitoring the design* consisted in providing pro-active support helping outline the design process and re-active support for ensuring readjustment of the design when necessary. Third, the possibility to enact designed resources (in France only) made it possible to test in a real setting the design choices, to get awareness that the design continues in use and in the case of some design teams to improve the resource in between two enactments.

The findings from our analyses however also point out several challenges the prospective teachers encountered in the design process. The fact that the designed resources were aimed at students not familiar with the digital technology to be used made them face a dilemma whether to target the introduction of the digital tool (instrumental learning goal) or a mathematical content. The instructors' feedback turned out to be critical in reorienting the design teams' educational goals. Another challenge the teams faced was classroom management of technology-based tasks. Often, students' technical difficulties were underestimated in the design and the enactment of the designed tasks took much more time than planned because of unforeseen students' mainly technical difficulties, obliging the teachers to make adaptations (design in use) that sometimes turned out not to be appropriate. Finally, although both resources relate uses of wide-spread digital technology that can be considered as rather classical from the research point of view (robust constructions with GeoGebra), the design of a digital resource during the course (and its enactment in the French case) represented a very first digital experience for most of the teachers; from their point of view, using GeoGebra with their students is a true innovation.

The DRDC framework that we elaborated is built on the concept of teacher design capacity (Pepin et al., 2017) extending it by highlighting components that are specific to the use of digital technology. It was applied to explore design capacity of prospective mathematics teachers who designed digital resources while benefitting from instructors' scaffolding and peer evaluation. Further research is needed to inquire if and to what extent the framework applies to studying in-service teachers design capacity on the one hand, and to informing teacher education and professional development programs.

## Appendix

### Resource template

[Title of the technology-supported activity]

**1. Identity card**

| |
|---|
| Professional question |
| Mathematical topic |
| School level |
| Teaching goal |
| Technology |
| Author(s) |

**2. Text of the activity (as it will be proposed to students)**

**3. A priori analysis of the activity**

- What is the student's task (what should they do)?
- What do students need to know (in mathematics and with respect to the use of technology) to be able to engage in the activity?
- What strategies the students can use? What is the expected strategy if there is one?
- What difficulties the students can encounter while solving the activity? What hints and feedback can be foreseen to face them?
- What is the role of the technology in the activity? What is its contribution?
- What can be put forward during the synthesis (institutionalization), in terms of mathematical and instrumental knowledge

**4. Implementation of the activity (pedagogical scenario)**

In the table below, describe the main phases of the planned enactment of the activity during a mathematics session. Please feel free to modify the table if you wish.

| Phase / duration | Goal | Modality/ instrumental orchestration | Role of the student(s) | Role of the teacher | Material support |
|---|---|---|---|---|---|
| Phase 1 5 min | Presentation of the activity | Whole class | Listen | Explain the tasks, asks reformulation | Projection on a whiteboard |
| . | . | . | . | . | . |
| . | . | . | . | . | . |

**5. Analysis of the enactment (a posteriori analysis)**

**6. Annex (if any)**

*Student worksheet, teacher's file, expected strategy, selected students' productions…*

### Peer evaluation template

#### Evaluation grid

To evaluate another group's project, you can use this evaluation grid. It is constructed around 4 criteria related to the description of the technology-based learning activity, the technology mobilized in the activity, the students' activity, and the teacher's role.

For each criterion, you assign your appreciation [very good (VG)—satisfactory (S)—fragile (F)—insufficient (I)] of each of the four aspects of the project. You are then asked to write a global appreciation of the project and suggest possible improvements.

Project of the group no:

Evaluation done by [name(s)]:

| Criteria | Appreciation (VG-S-F-I) |
|---|---|
| **Definition and description of the learning activity** | |
| Description of the learning activity | |
| Definition of the learning goal | |
| Mathematical and technical prerequisites | |
| Comment: | |
| **Relevance of the choice of technology** | |
| Rationale for the choice of the technology | |
| Relevance of the choice of technology with respect to the learning goal | |
| Added value of the technology in the learning activity | |
| Comment: | |
| **A priori analysis of the activity** | |
| Quality of the a priori analysis (does it enable to understand authors' didactic intentions?) | |
| Analysis of the ways of use of the technology by the students in relation with the target learning (does it help understand how the technology contributes to the target learning?) | |
| Relevance of the institutionalization with respect to the learning goal and to the students' activity | |
| Comment: | |
| **Role of the teacher** | |
| Planned didactic configuration related to technology (e.g., set up of parameters of the software) and to the articulation of different tools, digital and non-digital | |

| Criteria | Appreciation (VG-S-F-I) |
|---|---|
| Planned exploitation mode of the various tools, digital and non-digital (who uses which tool, when, with which purpose) | |
| Planned teacher's interventions oriented toward helping students' uses of technology (e.g., a sheet with a list of command and functionalities, technical demo) | |
| Comment: | |
| **Overall evaluation** | |
| Overall appreciation of the project | |
| Suggestions for improvement of the project | |

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## References

Arzarello, F., Olivero, F., Paola, D., & Robutti, O. (2002). A cognitive analysis of dragging practises in Cabri environments. *ZDM Mathematics Education, 34*, 66–72. https://doi.org/10.1007/BF02655708

Assude, T., & Gélis, J. M. (2002). La dialectique ancien-nouveau dans l'intégration de Cabri-géomètre à l'école primaire. *Educational Studies in Mathematics, 50*(3), 259–287. https://doi.org/10.1023/A:1021293215485

Becuwe, H., Tondeur, J., Pareja Roblin, N., Thys, J., & Castelein, E. (2016). Teacher design teams as a strategy for professional development: The role of the facilitator. *Educational Research and Evaluation, 3*(4), 141–154. https://doi.org/10.1080/13803611.2016.1247724

Beyer, C. J., & Davis, E. A. (2012). Developing preservice elementary teachers' pedagogical design capacity for reform-based curriculum design. *Curriculum Inquiry, 42*(3), 386–413. https://doi.org/10.1111/j.1467-873X.2012.00599.x

Binkhorst, F., Poortman, C., McKenney, S., & van Joolingen, W. (2022). Leadership in teacher design teams for professional development: Research synthesis and applications for coaches. *Irish Educational Studies*. https://doi.org/10.1080/03323315.2022.2148264

Borko, H., & Potari, D. (Eds.) (2020). *Teachers of mathematics working and learning in collaborative groups. ICMI study 25 conference proceedings*. National and Kapodistrian University of Athens.

Brown, M., & Edelson, D. (2003). *Teaching as design*. The Center for Learning Technologies in Urban schools: LeTUs Report Series.

Brown, M. W., et al. (2009). The teacher–tool relationship: Theorizing the design and use of curriculum materials. In J. T. Remillard (Ed.), *Mathematics teachers at work: Connecting curriculum materials and classroom instruction* (pp. 17–36). Routledge.

Drijvers, P., Doorman, M., Boon, P., Reed, H., & Gravemeijer, K. (2010). The teacher and the tool: Instrumental orchestrations in the technology-rich mathematics classroom. *Educational Studies in Mathematics, 75*, 213–234. https://doi.org/10.1007/s10649-010-9254-5

Drijvers, P., Grauwin, S., & Trouche, L. (2020). When bibliometrics met mathematics education research: The case of instrumental orchestration. *ZDM Mathematics Education, 52*, 1455–1469. https://doi.org/10.1007/s11858-020-01169-3

Drijvers, P., Tacoma, S., Besamusca, A., Doorman, M., & Boon, P. (2013). Digital resources inviting changes in mid-adopting teachers' practices and orchestrations. *ZDM, 45*(7), 987–1001. https://doi.org/10.1007/s11858-013-0535-1

Gueudet, G., & Trouche, L. (2009). Towards new documentation systems for mathematics teachers? *Educational Studies in Mathematics, 71*(3), 199–218. https://doi.org/10.1007/s10649-008-9159-8

Guin, D., Ruthven, K., & Trouche, L. (Eds.). (2005). *The didactical challenge of symbolic calculators: Turning a computational device into a mathematical instrument* (Vol. 36). Springer Science & Business Media.

Hamilton, E. R., Rosenberg, J. M., & Akcaoglu, M. (2016). The substitution augmentation modification redefinition (SAMR) model: A critical review and suggestions for its use. *TechTrends, 60*, 433–441. https://doi.org/10.1007/s11528-016-0091-y

Huizinga, T., Handelzalts, A., Nieveen, N., & Voogt, J. (2015). Fostering teachers' design expertise in teacher design teams: Conductive design and support activities. *The Curriculum Journal, 26*(1), 137–163. https://doi.org/10.1080/09585176.2014.990395

Jaworski, B., Chapman, O., Clark-Wilson, A., Cusi, A., & Esteley, C., Goos, M., Isoda, M., Joubert, M. & Robutti, O. (2017). In G. Kaiser (Ed.), *Proceedings of the 13th international congress on mathematical education* (pp. 261–276). ICME-13 Monographs. Springer. https://doi.org/10.1007/978-3-319-62597-3_17

Jones, K., & Pepin, B. (2016). Research on mathematics teachers as partners in task design. *Journal of Mathematics Teacher Education, 19*(2/3), 105–121. https://doi.org/10.1007/s10857-016-9345-z

Laborde, C. (2005). The hidden role of diagrams in students' construction of meaning in geometry. In J. Kilpatrick, C. Hoyles, O. Skovsmose, & P. Valero (Eds.), *Meaning in mathematics education* (pp. 159–179). Springer.

Pepin, B., Gueudet, G., & Trouche, L. (2013). Re-sourcing teacher work and interaction: A collective perspective on resource, their use and transformation. *ZDM, 45*(7), 929–943. https://doi.org/10.1007/s11858-013-0534-2

Pepin, B., Gueudet, G., & Trouche, L. (2017). Refining teacher design capacity: Mathematics teachers' interactions-sourcing teacher work and interactions with digital curriculum resources. *ZDM, 49*, 799–812. https://doi.org/10.1007/s11858-017-0870-8

Puentedura, R. R. (2006). *Transformation, technology, and education*. http://hippasus.com/resources/tte/puentedura_tte.pdf. Accessed 14 Mar 2024

Remillard, J. (2005). Examining key concepts in research on teachers' use of mathematics curricula. *Review of Educational Research, 75*(2), 211–246. https://doi.org/10.3102/00346543075002211

Rezat, S., Le Hénaff, C., Visnovska, J., Kim, O. K., Leroyer, L., Sabra, H., et al. (2019). Documentation work, design capacity, and teachers' expertise in designing instruction. In L. Trouche, G. Gueudet, & B. Pepin (Eds.), *The 'resource' approach to mathematics education* (pp. 323–388). Springer International Publishing.

Trgalová, J. (2022). Digital Technology and Its Various Uses from the Instrumental Perspective: The Case of Dynamic Geometry. In P. R. Richard, M. P. Vélez, & S. Van Vaerenbergh (Eds.), *Mathematics education in the age of artificial intelligence. Mathematics education in the digital era.* (Vol. 17). Springer.

Trouche, L. (2004). Managing the complexity of human/machine interactions in computerized learning environments: Guiding students' command process through instrumental orchestrations. *International Journal of Computers for Mathematical Learning, 9*, 281–307. https://doi.org/10.1007/s10758-004-3468-5

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