Introduction to How Digital Resources Alter Design Landscape

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Abstract

The main purpose of this section is to explore the design of and design with digital resources (DRs) for mathematics teaching and learning. Design of DRs involves teachers' engagement in the process where DRs are the product of design. Design with DRs refers to cases where DRs facilitate the design-work offering an environment for teacher collaboration (e.g., communication platform) or an environment for designing tasks and lessons. The chapters of this section address both forms of design.

Keywords

Digital Curriculum Resources · Digital resources · Teacher collaboration · Teacher design · Teacher professional learning

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Introduction

Over the last years, there is a gradual transition of the research interest from resources used by teachers and/or teacher educators to the availability and use of DRs (cf. Pepin et al. 2017; Trouche et al. 2020). At the same time, new digital means, for example, e-textbooks offering new potential structures to the teacher and new interactions with the users influence teachers' work (in and out-of-class) both at the level of design and professional development. The nature of the current mediating technologies and the availability of DRs are at the core of research studies aiming to address the ways by which the wide spreading digitalization of resources influences the design landscape at the level of teachers, teacher educators, researchers, and other professionals engaged in the process of designing DRs (software designers, artists, etc.) (cf. Clark-Wilson et al. 2022; Leung and Baccaglini-Frank 2017). A basic assumption of these studies is that the multiplicity of the DRs favoring experimentation with dynamic and interrelated mathematical representations – both individually and collectively – offers increased opportunities for teachers to design their lessons and modify the teaching approaches traditionally adopted in the classroom. Also, the study of teachers' work taking place in diverse contexts and communities raises questions of the collective/collaborative dimension of design at all educational levels.

The above issues are addressed in this section through different theoretical lenses and qualitative methodologies attempting to capture the process and the outcome of design as well as its impact on teacher professional development and student learning. The ten chapters of this section illustrate different ways by which researchers have studied teacher design of/with DRs highlighting the state-of-the-art in this area over the last decade. These chapters address a number of key questions that reflect the interests of the research community in the area of designing DRs, or with DRs. The questions can be synthesized as follows:

- What are the features of DRs that can be used by the teacher to create rich learning opportunities for students?
- How advances in computer technology can be exploited in the design of digital environments for mathematics education?
- What are the design features of digital assessment platforms so as to assess complex mathematical thinking?
- What are the design features of DRs that can support mathematics teachers' planning of and enacting teaching and learning activities?
- How do DRs mediate mathematics teacher collaboration in planning and enacting teaching?
- How do different stakeholders collaborate to design DRs?
- Under which approaches can the quality of DRs be evaluated?

The chapters have been classified in four strands on the basis of their content: designing DRs for promoting and assessing students' mathematics learning;

designing DRs to support teacher planning and classroom teaching; designing DRs from a collective perspective; and evaluating the quality of DRs.

Below, we provide a brief presentation of the chapters and their contribution to address these questions. The chapters are discussed within the strand (research theme) in which they have been classified.

Designing DRs for Promoting and Assessing Students' Mathematics Learning

Three chapters have been classified in this strand.

Leung, Baccaglini-Frank, Bokhove, Nagari-Haddif, and Yerushalmy discuss the design principles of Digital Curriculum Resources (DCRs) emphasizing their complex structure needed for exploiting the affordances of digital technologies so as to offer students opportunities for engaging in rich mathematical activity. The digital features addressed in this chapter concern: the task and task design, the feedback mechanism, the shared learning space, and the connectivity. The authors first define these characteristics and then illustrate them through three research examples. The first example concerns the design of a mathematics e-textbook, the second one the design of an online formative assessment platform, and the third one the online class discussion guided by a teacher in a DCR platform. The example about the design of a mathematics e-textbook addresses the importance of designing tasks that allow students to engage in meaningful activity but also in deep mathematical thinking. However, to achieve the above goal, the authors identify tensions that the designers need to handle such as (a) the openness of the environment against its guided features, (b) the addition of new tools supporting interactivity against the utility of these tools, and (c) reducing the workload against the constraints in problem solving. The second example concerns the design of online assessment where the emphasis is given on using assessment tasks to address the complexity of students' mathematical understanding. In particular, three central design principles are proposed. In the first principle, the goal is the design of eliciting tasks that on one hand constrain the mathematical object of study and on the other ask for multiple students' generated examples. The second principle concerns the design of tasks favoring concepts' connectivity, while the third principle suggests different input forms and interactions. The shared learning space that promotes mathematics discussion is addressed in the third example. The communication platforms and the relevant tools (e.g., online chat, use of microphone for online gesturing and inviting invisible students) can offer opportunities for mathematical discussions. Finally, through the three examples, connectivity is addressed in the tools (e.g., varying the tasks, the pool of students' generated examples, the dynamic functionalities of the platform) that offer opportunities to students to build connections between key mathematical concepts and representations. Moreover, the orchestration of the online classroom discussion by the teacher through the use of DCRs promotes socio-constructive connectivity.

Lagrange, Richard, Vélez, and Van Vaerenbergh present state-of-the-art examples of the design of digital environments for mathematics education focusing on Artificial Intelligence (AI) techniques. The analyzed projects show how designers handle the tension between, on the one hand, the users' point of view, the epistemology of mathematics, and the way they are taught, and on the other hand the possibilities and constraints created by advances in computer science. The AI techniques concerning symbolic approaches and machine learning are discussed about (a) interconnecting Computer Algebra Systems (CAS) and Dynamic Geometry Systems (DGS) in the context of automatic modeling using geometrical calculation in the Casyopée environment and (b) automated proof generation integrating a DGS interface with dialogical interfaces to develop mathematical argumentation through the use of logic programming in the QED-Tutrix intelligent tutoring system. Next, four categories of Machine Learning techniques are briefly described: information extraction, automatic reasoning, explanation, and data-driving modeling. The chapter concludes with a discussion on modeling knowledge and learner activity, and the differences between AI symbolic techniques and machine learning techniques. The internal analysis of DRs for mathematics education carried out in this chapter indicates the kind of awareness of the inner functioning of AI-based systems that is needed in order to progress in the design of digital environments for mathematics education. The authors, who are all researchers in mathematics education, highlight the need for a multiyear perspective taking into account mathematics education theoretical frameworks instead of a short-term focus on the latest applications claiming to be powered by AI.

Olsher, Chazan, Drijvers, Sangwin, and Yerushalmy explore assessment performed automatically by three content specific digital platforms. They focus on the design decisions found in these platforms and propose three interrelated design considerations that help map the development of digital assessments: design of tasks and tools for student mathematical work, interpretation and analysis of student work, and reporting of analysis results. The authors conclude with some remarks on the current status of automatic assessment of students' mathematical work. Specifically, they stress that the tasks that are assessed automatically are often related to calculations (e.g., factoring) and there is a mismatch between digital assessment and competencies of "doing mathematics." Also, they see a merit in integrating data analytics into mathematics education, stressing the need for fit between the information collected and production of insights that will improve the learning of mathematics in classrooms. Finally, they emphasize the importance of continued engagement of mathematics education community with the design of digital assessment platforms. The intention is to preserve a content specific focus on higher level thinking in mathematics as well as to support goals important to improving students' mathematical thinking. This point is also discussed in relation to the designer's difficulty to keep a balance between students' convenience in interacting with the tools and the ability of a platform to identify and analyze students' mathematical work. In their conclusion, the authors recognize the limits in assessing complex mathematical thinking through online automatic tools and highlight the need for solutions that are custom made to specific needs of assessment of complex mathematical activity.

Designing DRs to Support Teacher Planning and Classroom Teaching

Three chapters have been classified in this strand.

Under a Documentational Approach of the Didactics (DAD) perspective, Gueudet, Pepin, and Rezat address the role of resources supporting lesson planning and teaching. For this, they introduce the notion of *meta-resource (MR)* and define it as a material resource, which has been explicitly designed for supporting mathematics teachers' planning of teaching and learning activities. In the chapter, they present a classification of meta-resources identified in the literature according to six design aims: choosing resources; designing learning progressions; designing lesson plans individually; task design; assessment design; and designing collectively in the context of professional development. After a review of the literature around these aims, they conclude that MRs constitute an important element in teachers' design landscape and that digital MRs contribute to the transformation of this landscape in two ways. First, digital MRs can facilitate teachers' choice of resources in an increasingly complex landscape of available resources, and second, digital MRs can offer new possibilities for teachers' individual and collective planning of teaching and learning activities through the use of different media and authoring tools. Identified constraints imposed by digital MRs on teachers' planning activities can be linked to the educational aims of teachers' documentation work (e.g., use of teacher guides in specific national contexts) or restrictions of choosing a teaching objective from a predetermined list. Areas of further research include: the kind of professional knowledge on tasks and lesson plans for teachers that is represented and mediated through MRs; the balance between opportunities and usability of authoring environments for task design for teachers; and the interplay of the MRs in teachers' MR-systems.

Visnovska, Cortina, and Eckert argue against the designing of a resource with the focus on students' learning directly. Alternatively, they support the need to consider into the design the complexity of teaching and how the teachers could be supported in using these resources into planning and enacting lessons. Supporting teachers does not mean to instruct them on what to do in their classrooms but to support teacher decision making by helping them to understand the rationale of the resource. The designers need to see teachers as professionals who co-design, with resources aiming to support their students' learning of mathematics. The authors offer two examples of their collaborative design work in (a) adapting a resource for primary school from the US context to the Mexican context in digital format and (b) designing a short teaching sequence for secondary school teaching with the use of digital tools in Sweden. They illustrate through these examples how they conceptualize the meaning of "designing for teaching" and they substantiate their framework in achieving this. In their framework, they identified three characteristics of the resource design so that to become a part of a teacher's repertoire: the relevance and the clarity of the resource to the teacher as well as the resource viability in the teacher's classroom. The relevance and the clarity can be achieved when the designers attend to the classroom realities and to the institutional context of teaching.

The viability of the resource can be tested through design research in implementing the resource in the classroom with the students' learning as primary goal.

Mariotti, Trgalova, Maracci, and Højsted focus on how the designer of a didactical material aiming to help teachers integrate DRs in their teaching can help the teacher to evaluate its didactical potential and to enact it. Under a DAD approach, the authors consider the resource as a relational object that expresses the relationship between the designer, the intended user, and the proposed resource. They also consider instrumentation and instrumentalization processes intertwined with the appropriation of a DR by the teacher as well as the utility, usability, and acceptability as dimensions of evaluation of the resource. Building on these interrelated perspectives, they develop a triadic structure (sequence, guidelines for the activity management, rationale) for the designer to consider so as communicating to the teachers the didactical potentialities of the resources and support them in both evaluating and enacting these DRs. The authors recognize the paradox between providing a lot of details to the teacher "too complete" and guided or "incomplete" information that may allow more agency from the side of the teacher but also make harder the implementation. They recommend the designer to maintain a reasonable balance between the above two directions.

Designing DRs from a Collective Perspective

Three chapters have been classified in this strand.

Essonnier, Barquero, Papadopoulos, Trgalova, and Kynigos focus on the collaboration of DRs' designers belonging to diverse communities aiming to promote *creative mathematical thinking (CMT)* among students. In particular, the emphasis is given on a methodological approach that first examines constraints but also facilitation of the collaborative design and second illustrates how digital technologies can influence the collaborative design of DRs. The study considers creativity in a design group (social creativity) as essential for promoting mathematical creativity among students. In particular, the authors study small groups of designers in three different educational settings (France, Spain, and Greece) who collaboratively design DRs to promote students' mathematical creativity. Using boundary crossing and instrumental theory, they scrutinize into the redesign processes of a digital book. For example, the collaboration of the Spanish and Greek communities indicated boundaries and boundary crossings related to different educational contexts as well as to different research approaches and epistemologies. Under the lenses of instrumental genesis, they explore the role of two artifacts (a CMT grid and a collaborative workspace) on the social creativity of the Spanish and French design teams. The CMT grid helped the communities to evaluate the CMT opportunities that the digital book provided while the collaborative workspace contributed to considering constantly the goals of the design and to reach convergences. The complementarity of the two theoretical perspectives allowed both the focus on the process of collaboration around a boundary object (the digital book) and the important role of the digital sociotechnical environment (the two artifacts) in this process.

Under the framework of Meta-Didactical Transposition, Taranto, Aldon, Robutti, and Cusi analyze teachers' engagement in designing resources for teaching through two Massive Open Online Courses (MOOCs) in two professional development programs taking place in different national contexts (France, Italy). The authors explore the role played by the DRs designed by didacticians in fostering and supporting internalization processes when the teachers interact with them within MOOCs. The processes of internalization characterized the evolution of teachers' didactical and meta-didactical praxeologies and emerged as a result of teachers' engagement in analyzing, designing of, and implementing three types of resources: technological (e.g., mind map software), methodological (e.g., tools for designing assessment), and content resources (e.g., tasks within thematic modules). A main finding of the study is that internalization was boosted by teachers' interactions with didacticians, with other teachers and with different types of resources from the aforementioned types. Areas of further research include how to identify the level of internalization that is observed within a MOOC as well as the ways in which the internalization processes are related to teachers' participation in a MOOC.

Psycharis, Potari, and C. K. Skott address the interplay between collective and individual aspects of teacher design in collaborative settings through a systematic literature study. Their focus is on the context, the product, the purpose, and the processes of teachers' design-work and its impact on their professional learning when participating in collaborative work with DRs. They also focus on the theoretical and analytical perspectives that are used by researchers to study teachers' collective design-work with DRs. The results are structured around two main themes concerning the process of teacher collaboration and the impact of teacher collaboration on teacher professional learning. The final synthesis indicates that teachers' collaborative design-work has usually positive learning outcomes for individual teachers; individual teacher learning-gains are related to the transformation of design and teaching practices; and the role of DRs in the collaboration depends on their affordances. Areas of further research include the collective-individual interplay with a focus on the contribution of the individual teacher to the collaboration and study of individual teacher learning over time and in relation to students' learning.

Evaluating the Quality of DRs

One chapter has been classified in this strand. Trgalova, Donevska-Todorova, and Edson focus on the concept of quality of DRs and they use examples from different educational contexts to illustrate existing approaches to quality evaluation. Such approaches include types of resources, intended evaluators, purposes, and frameworks/criteria. The main question as regards evaluation of DRs addressed by the chapter concerns the how and what for? For the "how" question, the overview of research studies shows a multiplicity of ways to evaluate the quality of DRs. Also, the developed frameworks and criteria are often not subject-

specific, very much dependent on the types of resources (not conclusively DRs) and rather complex to use. For the "what for" question, the identified purposes of digital resource evaluation converge toward supporting teachers to: access quality teaching resources, select the most relevant resources, understand better their teaching and learning potential, and create their own ones. Multidisciplinary approaches involving computer science, AI, and machine learning are recommended as ways to address issues related to the quality of DRs emerging from the rapid development of digital technologies and go beyond mathematics education. Also, quality is suggested to be considered in relation to issues such as equity, fairness, big data, ethics, and diversity.

Concluding Remarks and Future Perspectives

Synthesizing the above contributions in relation to the posed seven questions at the beginning of introduction, we provide some answers drawn from the chapters to show current research directions in the area of designing of/with DRs. The focus on how the design of/with DRs can promote students' learning seems to be central. The main question about learning is in what ways DRs can promote rich mathematical experiences to students. This appears to be a challenging goal for the designer that is still open for further research. However, current research provides outcomes that contribute to this goal such as new feedback mechanisms, shared learning spaces, task design and enactment favoring mathematical argumentation and connections between mathematical concepts, new techniques of AI that can be exploited in the design of digital environments for mathematics education, and design decisions for online assessment systems focusing on higher level thinking in mathematics. Future research needs to consider how DRs can be integrated in diverse contexts taking into account the continuous advances of computer technologies and preserving the learning priorities indicated by mathematics education research.

Another main question concerns the design features of DRs that can support mathematics teachers' planning of and enacting teaching and learning activities. Current research studies bypass instructive approaches targeting teachers' active engagement in lesson design based on the complexity of actual classroom teaching. The main question concerns how design of DRs could help teachers to understand their rationale and evaluate them in relation to their didactical needs. The chapters of section 6 that address this question provide some answers. For instance: relevance and clarity of the resource should be close to classrooms realities; testing a resource through implementation is another way to learn about its viability; the structure sequence-guidelines for the activity management-rationale offers a way to communicate with the teachers the didactical potentialities of the resources. Areas of further research may concern teacher knowledge mediated through DRs for teaching and how to keep a balance between opportunities and usability of DRs for teachers.

Designing DRs in collaborative settings is another area attracting the research interest. The main research questions address the process of and/or the outcome of collective design of DRs in diverse communities. Concerning the process, DRs play an important role in the collaboration while boundaries emerging in this context and their handling have an impact on the outcomes of the collaboration. In relation to the outcomes of collective design, current research shows that there are learning-gains for the participants in terms of design and teaching practices. Future research needs to develop theoretical and methodological tools to study the collective-individual interplay in the actual process of collaboration.

Concerning the evaluation of the quality of DRs, it is related to the enactment of DRs in actual teaching and to their learning potential for students. Supporting teachers to become aware of these features is a priority for the designers. Future research should take into account technological advances as well as broader contextual issues.

Overall, the chapters of section 6 provide some answers to the role of DRs in the design landscape. They indicate current trends in this research area and highlight new directions for further research. New theoretical and methodological tools are needed to address a multiplicity of issues inherent in linking design of/with DRs and actual teaching.

Cross-References

- ▶ Addressing Collective and Individual Aspects of Teacher Design with Digital Resources in Collaborative Settings.
- ▶ Artificial Intelligence Techniques in Software Design for Mathematics Education.
- ▶ Communities of Interest as a Context for Creativity in the Process of Designing Digital Media for Mathematical Learning.
- ▶ Design of Resources for and by Mathematics Teachers: The Process of Internalisation in MOOCs.
- ▶ Digital Assessment and the "Machine".
- ▶ Digital Curriculum Resources in Digital Mathematics Curriculum: Design Features and Implementation.
- ▶ Evaluation of Digital resources: The "How" and "What for".
- ▶ Meta-resources: Supporting the Design of Mathematics Teaching and Learning.
- ▶ Resource Design for Re-sourcing Teaching.
- ▶ Resources Promoting Digital Tools Integration: Design Principles.

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