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Online professional development for teaching algebra: Towards the design of an asynchronous, adaptive self-learning module

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As a way to offer more flexible and easier to access in-service support, the number of online teacher professional development programmes (oTPD) has rapidly grown over the past decade. The COVID-19 pandemic, however, has added a new level of urgency to the participation in oTPD so that research has largely not been able to keep pace with the design and delivery of such programmes. There is, consequently, a lack of empirical evidence regarding optimal characteristics for the effective support of teachers' professional online learning, and also a need for more research on how professional growth can be assessed in this context. We aim to address this research gap in the context of the German professional development project MaCo (Catching up in mathematics after COVID-19). In this paper, we describe the design elements of an asynchronous self-learning module for teaching algebra including the development of a vignette-based test for assessing related learning outcomes.

Keywords: Online professional development, algebra, video, cartoon, vignettes.

Introduction

Online professional development can be defined as structured, formal professional learning that is provided entirely online, aiming at a change in teacher knowledge, behaviour and practices (Bragg et al., 2021). In 2009, a first research agenda for online teacher professional development (oTPD) was published by Dede and colleagues. Already at this time, online formats were assumed to better fit with teachers' busy schedules, drawing on resources that might not be available locally and that can provide on-going and work-embedded support for in-service teachers. Furthermore, oTPD were considered as potentially more scalable to spread quality development programmes, also in the context of educational reforms. The 2009 review of empirical oTPD studies provided by Dede and his colleagues revealed, however, that most of the 40 studies reported only findings *whether* a specific programme worked or not - often without providing any evidence to explain *why* (Dede et al., 2009). Moreover, most studies used only self-report data as outcome measures or were designed for a very specific context so that findings were hard to transfer. Consequently, the authors called for more systematic research in this area, also with methods that take advantage of the unique data collection possible in online formats (Dede et al., 2009). Current literature reviews (e.g., Lay et al., 2020; Bragg et al., 2021) highlight the great potentials of oTPD such as improved access, flexibility and lower cost, also in light of the COVID-19 pandemic. However, the authors of these reviews have to conclude that while understanding evidence-based design elements of successful oTPD programmes appears to be vital, the explosive growth of oTPD programmes still outpaces rigorous empirical research in

the field (e.g., Bragg et al., 2021). We aim at addressing this gap in research in the context of the German professional development project MaCo (Catching up in mathematics after COVID-19). The development of the asynchronous self-learning module we will report on in this paper aims at enhancing in-service teachers' pedagogical content knowledge and noticing in the content area of algebra, a key curriculum topic on secondary level (12–15-year olds). Based on the research agenda suggested by Dede et al. (2009), we are particularly interested in how an asynchronous online module can be designed to provide teachers with effective learning opportunities and what measures of effectiveness can be used to document the outcomes of such an oTPD.

In the following, we will first explain more about the difficulties many students face when learning algebra underpinning the essential role of quality teacher professional development for effective student support. We will then review current empirical evidence on oTPD programmes and derive essential design elements for the online self-learning module. After outlining the research questions, we will describe the context, contents and design elements of the online module and related research based on an offer-and-use model for teachers' professional development (Lipowsky & Rzejak, 2015).

Difficulties in learning algebra and teachers' essential role for student support

Algebra is a powerful and indispensable tool for doing mathematics and it is often viewed as a gatekeeper to higher-level mathematics. At the same time, students often make mistakes while executing algebraic operations and many find it hard to trace their errors or improve their performance. Also, students who are able to perform specific algebraic procedures often attach little meaning to them, and may be lost when a problem situation is slightly changed (Drivers, 2003). Up until the second half of the twentieth century, algebra was viewed as the science of equation solving and corresponding research focused mainly on difficulties in solving various types of equations or on students' errors in applying equation-solving algorithms (Kieran, 2020). The traditional method of teaching algebra has often been criticised: too much emphasis on symbols, on manipulative skills and on algebraic facts rather than on concept development and problem-solving skills. As a matter of fact, algebra lessons and contemporary definitions of school algebra can vary considerably around the world, not only in terms of content but also as to whether the main focus is either procedural or conceptual or some combination of the two (Kieran, 2020). Contemporary definitions of school algebra do, however, mostly not only include sign-based activity involving mathematical objects and the relations between them, but also the seeking of structures, the expression of generalisations, the use of multiple representations, problem solving, the modelling of real situations and the use of digital tools (Kieran, 2020). Algebraic reasoning as the mathematical thinking processes underpinning related activities has moved into the focus of research, considering different factors and sources by which students derive meaning for algebraic objects and processes (Kieran, 2020).

However, studies related to the learning of algebra have continually provided evidence for the high cognitive effort involved in doing and in being successful in algebra (Kieran, 2020). It has, for example, often been reported that students find it hard to relate formal algebraic procedures to more informal and meaningful approaches and that they frequently struggle with the formal algebraic language and the abstract level at which problems are solved (Drivers, 2003). Alongside with these findings, there is a broad consensus that the teacher plays an essential role in supporting students'

algebraic thinking and how students make meaning of algebraic objects and processes (Kieran, 2018). Accordingly, teaching algebra requires the teacher to carefully design tasks, to prompt structuring and generalising activities and to listen, question and respond appropriately to students' efforts in activities developing their algebraic thinking (Kieran, 2018).

To be able to provide students with such optimal support, teachers do not only need professional knowledge, e.g., about the development of algebraic thinking and students' typical misconceptions and difficulties in this content area. As an essential prerequisite for informed decision-making (e.g., how to support a student in his/her understanding), teachers are also required to apply such knowledge to classroom situations by identifying and interpreting what they observe (e.g., a certain difficulty or misconception). We described that process of identifying and interpreting in our prior research as teachers' analysing of classroom situations (e.g., Friesen & Knox, 2022; CERME12 proceedings), based on the concept of Teacher Noticing (Sherin et al., 2011). For the presented online self-learning module, we build on that research, mainly for the vignette-based assessment of teachers' pedagogical content knowledge related to algebra, as will be explained in the sections below.

Online teacher professional development: What works and what is still missing?

In general, it can be assumed that quality criteria for effective face-to-face professional development are also valid for oTPD programmes, e.g., addressing core practices of teachers, engaging teachers in in-depth content learning and reflection or supporting teachers' professional learning with feedback (Lipowsky & Rzejak, 2021). However, it has also been acknowledged that developing oTPD programmes according to these criteria might involve specific requirements and challenges that have to be considered when making corresponding design decisions (Bragg et al., 2021). We will consequently first take a look at current empirical evidence on effective oTPD programmes, focusing on asynchronous formats as planned for the presented algebra self-learning module. In a systematic literature review by Bragg et al. (2021), the following oTPD design elements were reported to result in productive learning outcomes, such as increased knowledge and improved practice, but also in learner satisfaction and reduced drop-out rates:

- Addressing teachers' pedagogical content knowledge: providing knowledge needed to make subject matter comprehensible to students
- Goal-orientation: includes learning-goal oriented activities and content
- Relevance: considers teachers interests and self-identified learning needs through the provision of different relevant resources
- Flexibility: provides opportunities to engage in self-directed learning where participants study content they choose at their own pace
- Considering individual learner differences: differences in online learning and teaching experience; differences in learning preferences by differentiated activities (reading, watching video, practice new skills)
- Application of knowledge: requires teachers to connect and apply newly developed knowledge to the teaching context
- Fostering participant engagement: in asynchronous formats e.g., through interaction with the Learning Management System or with peers using discussion boards

- Practical learning activities: embeds practical activities or real-life observations in the online learning material
- Reflection: encourages continuous reflection on content and learning experience
- Providing learner support, e.g., through learner–computer activities (e.g., interactive tools, evaluation reports, feedback)

One of the major limitations described by the authors of the review is, however, that the reported design elements were often not described and discussed in sufficient detail (Bragg et al., 2021). The authors identify this as a clear research gap, together with a lack of descriptions related to user experience (UX) and learning experience (LX) when participating in oTPD. Another key finding of the review is that theoretical frameworks of adult learning theory applicable to oTPD programmes (such as self-directed learning or self-determined learning) or references to frameworks for teachers' professional growth were either missing or not explicitly stated in the reviewed studies.

Main research questions and an offer-and-use model for research on oTPD

Aiming at contributing to the empirical evidence needed for the design of effective oTPD programmes, we will address the following main research questions: How should asynchronous oTPD programmes be designed (e.g., contents, methods of delivery, platform, user interface) to provide effective learning opportunities for in-service teachers? How do teachers make use of asynchronous oTPD programmes (e.g., time spent online, user and learning experience)? What measures of effectiveness can be used to document the outcomes of such programmes (beyond self-report)? Regarding a framework for investigating the research questions outlined above, we can build on a current study into asynchronous oTPD (Demmler et al., 2022) based on an offer-and-use model for research on teacher professional development (Lipowsky & Rzejak, 2015). According to that model (Figure 1), different factors such as the quality and quantity of learning opportunities, their perception and usage by the participant, participants' individual characteristics and the support provided by the facilitator are supposed to influence the success of a professional development programme. Also considering interactions among these different factors, the offer-and-use model for research on teacher professional development allows the more systematic investigation of questions regarding, for instance, the interdependence between particular design elements on the side of the offer and the utilisation of provided content on side of the user, depending, e.g., on a user's prior knowledge or motivation.

For the current development of the self-learning module for teaching algebra, we focus on the model parts highlighted in Figure 1, aiming to investigate outcomes on level 1 (participants' acceptance and satisfaction, also important to prevent the participants' drop out) and level 2 (enhancement of pedagogical content knowledge and noticing related to the teaching of algebra). In the presented online context, activities usually provided by a facilitator (e.g., providing feedback, encouraging reflection) have to be taken over by online activities within the Moodle platform in the best possible way.

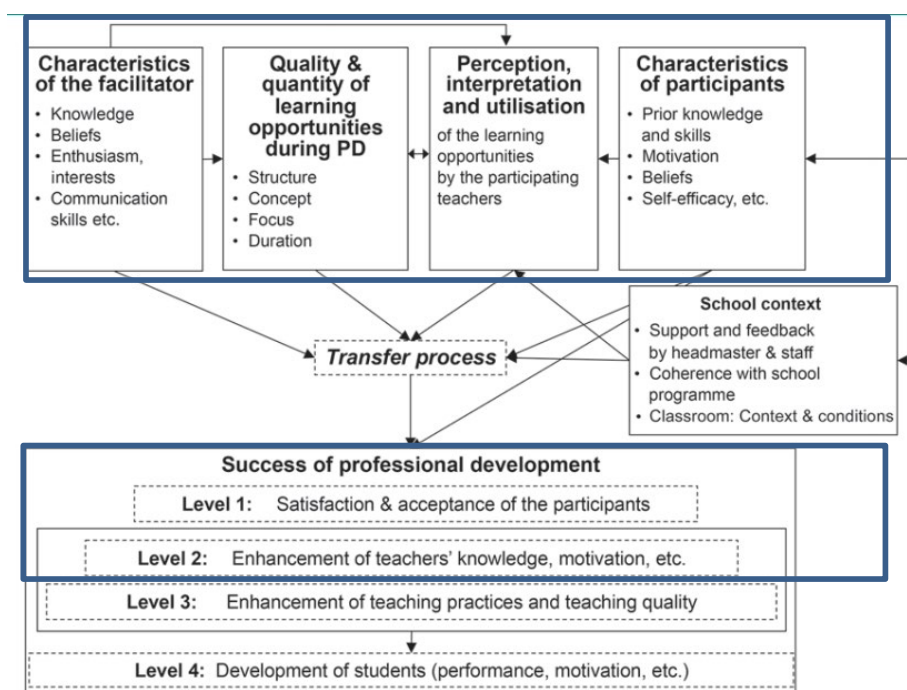


Figure 1: Offer-and-use model for research on teachers' professional development (highlighting boxes added by the authors) (Lipowsky & Rzejak, 2015, p. 30)

In the following section, we will first introduce the context and aims of the MaCo project, before we describe the content and design elements of the algebra self-learning module.

Context, content and design elements of the online self-learning module

With the aim to support teachers in helping their students to catch up in mathematics after the COVID-19 pandemic, the MaCo project offers research-based material for assessing and supporting students' understanding in key topics of the primary and secondary maths curriculum. Additionally, free content-specific synchronous online sessions (90 min) were offered for introducing the material and for further support. These synchronous online formats are planned to be complemented by asynchronous self-learning modules: available long-term on a Moodle platform at teachers' individual need and convenience, providing just-in-time assistance. The MaCo project provides thus the larger context for the development and programming of the Moodle-based online module on teaching algebra that we present in this paper.

According to the design elements reported above (Bragg et al., 2021), effective oTPD should have a particular content focus and address professional knowledge relevant for teachers' classroom practice. Regarding the contents of the self-learning module, we can draw on an already existing face-to-face algebra module, developed and evaluated for teacher professional development in the German context (Abshagen et al., 2019). This face-to-face module is based on a thorough analysis regarding the algebraic objects and processes students have to learn and understand and also regarding what teachers have to know to support students in the development of their algebraic thinking, as described above (see also Barzel et al., 2021). Accordingly, we chose to structure the algebra content for the online self-learning module into three parts: variables, terms and equations. For each of the parts, we

selected three key topics related to students' learning of variables (e.g., variable as unknown and changeable; misconceptions: variable not as quantity but as object), terms (e.g., setting up terms from patterns and situations; check if different-looking terms represent the same, linking among multiple representations) and equations (e.g., concepts of equality sign; different approaches to solving equations, equivalence) and identified teachers' related pedagogical content knowledge and practices (e.g., selecting rich tasks; selecting examples and situation contexts; assessing typical misconceptions; supporting students in linking multiple representations, teaching for conceptual understanding and not only for procedures, etc.) (see also Abshagen et al., 2019; Barzel et al., 2021).

The design elements introduced above (Bragg et al., 2021) suggest that effective oTPD is characterised by the provision of different relevant resources, also video and practical materials; offering different activities fostering reflection and interactive tools providing feedback. To implement these aspects in the context of the algebra self-learning module, we chose video as suitable format to present the selected content to the oTPD participants. Accordingly, we developed nine video scripts for recording input videos that will each last about 15-20 minutes. The videos will feature authors from this paper as speakers and they are all structured in a similar way. Based on the design elements reported above (Bragg et al., 2021), each input video includes: activities addressing typical situations and material from everyday classroom practice (e.g., analysing a student's solution or reacting to a particular mistake), theoretical input clearly linked to the content and topics outline above, an interactive H5P-quiz (a Moodle quiz format for videos) providing the opportunity to apply knowledge in a typical professional situation (e.g., analysing the potential of a task for supporting students' conceptual understanding) and optional feedback for the quiz.

Based on the design elements reported above, we aim at adapting the offer of input videos to individual learning prerequisites (see also Lipowsky & Rzejak, 2015) and at investigating the participants' professional growth beyond self-report measures (see also Dede et al., 2009). Accordingly, we aim at assessing the participants' prior knowledge when they start and when they finish the self-learning module with the same set of nine cartoon vignettes. Using teachers' responses to representations of practice or so-called vignettes has proven to be a valid measure in this context and we can build on our prior research into the vignette-based development and assessment of teachers' professional knowledge and noticing (e.g., Friesen & Knox, 2022; Friesen & Dreher, accepted): Vignettes represent typical classroom situations (e.g., student-teacher interaction around a task or question) and are complemented by particular prompts in order to elicit and guide teachers' noticing (see Sherin et al., 2011 for the concept of teacher noticing). The responses can then be taken as measures for teachers' ability to apply professional knowledge to a situation, e.g., by correctly identifying and interpreting a typical misconception that students can hold when developing algebraic thinking.

Accordingly, we developed for each of the nine input videos a matching cartoon vignette. Cartoon-based vignettes, in particular, can easily be designed and varied (see Friesen & Knox, 2022) to match particular content and learning goals, as we provide in each of the nine input videos. Each of the vignettes comes with four multiple-choice items asking the participating teachers, e.g., to evaluate different teacher reactions to a student question, representing different approaches (here: based on the theoretical background on learning and teaching algebra outlined above, e.g., related to the fostering

of more procedural or more conceptual knowledge, a combination of both or a merely pedagogical approach). According to the participants' answers, they will receive recommendations by the Moodle platform only for those input videos they did not succeed in responding to; but will also be able to watch the other videos. With these design considerations, we aim at adapting the learning offer (here: input videos) to the participants' learning prerequisites while also providing them the option to select content according to their interest. We hence applied the design elements related to relevance and flexibility, for instance, giving the participating teachers the option to choose their own pace of learning based on feedback which relates to their learning progress; an important aspect of successful professional learning that would usually be provided by a facilitator in face-to-face programmes

After finishing the online self-learning module, the participants are asked to respond to the same set of vignettes a second time and they will be able to compare their responses from the beginning and end of their learning with the algebra module. The platform will also offer access to short explanations about the desired responses providing further opportunities for feedback and reflection. All in all, the cartoon vignettes can serve several purposes for teachers' learning with the algebra online module: The vignettes provide the participating teachers with the opportunity to assess their prior knowledge when starting the module, to receive feedback and to decide about which content they want to learn about and when; the vignettes engage the participants in connecting and applying newly developed knowledge to authentic teaching contexts and the participants will be provided with a feedback on their learning outcomes when finishing the online module; all aligning with the design elements for effective oTPD reported above (Bragg et al., 2021; Lay et al., 2020).

Discussion and next steps

In this paper, we aimed at introducing an asynchronous, adaptive self-learning module for the teaching of algebra as online learning opportunity for in-service teachers. We develop this module based on empirical evidence on oTPD and aim at investigating its use and effect based on the offer-and-use model for teacher professional development. A first evaluation of the cartoon vignettes in interviews with experienced in-service teachers showed that the presented classroom situations are perceived as typical, authentic and motivating to engage with. More work has to be done before the self-learning module can be presented online, both on the side of design decisions, evaluation and steps in the technical programming of the Moodle platform. However, the systematic design and investigation of such online formats is key for offering effective oTPD programmes. Asynchronous formats appear to have great potential in this context: they do not only respond to individual, self-paced learning needs of in-service teachers, but they also generate productive learning outcomes (Bragg et al., 2021) and support systematic research by allowing for the controlled implementation of learning materials and the investigation of usage behaviour (Dede et al., 2009).

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