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Designing mobile environments for mathematics distance education: The theory-driven development of the ASYMPTOTE system

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Distance teaching and learning due to the Covid-19 pandemic was perceived as a major challenge by both, teachers and students. With new ways of instruction emerging in a matter of days, the resulting instruction formats – summarized in the term Emergency Remote Teaching (ERT) - could not fully meet the needs of online teaching and learning in Spring 2020. With a particular focus on the reported problems of mathematics distance education during the Covid-19 pandemic, this paper firstly aims at providing a theoretical framework for the development of mobile environments for distance math class. In doing so, we refer to the Community of Inquiry (CoI) model and e-pedagogy to deduce design requirements for online learning environments. Secondly, the ASYMPTOTE system is introduced. Based on the theoretical considerations and the discussed Covid-19 experiences, necessary further developments and requirements for the project are identified.

Keywords: Covid-19, design requirements, distance education, mobile learning, online systems.

In the following, a theoretical framework for mobile learning environments aiming at mathematics distance education is provided. Hereby, we refer to the Community of Inquiry, online learning and practices of online instruction as well as mobile learning. The theoretical framework is used to evaluate the present status of the ASYMPTOTE system and to identify needed further developments.

Theoretical Framework

Community of Inquiry

A well-known approach for the design of digital educational environments is the Community of Inquiry model (CoI), which is based on Dewey's (1897) assumptions made on the value of social interaction and collaboration to the learning process. The constructivist model describes learning in online communities – composed of teacher and students – by the interplay of three core elements: cognitive presence, social presence and teaching presence (Garrison et al., 2000).

Cognitive presence in online environments is considered as a holistic multi-phased process initiated by a triggering event. According to the practical inquiry model, it is followed by an individual exploration which result in a reflection process – and thus in the creation of new concepts. Afterwards, the skills and knowledge acquired are practiced in real situations (ibid.). Thus, cognitive presence is defined "as the exploration, construction, resolution and confirmation of understanding through collaboration and reflection in a community of inquiry" (Garrison, 2007, p. 65).

Social presence describes the ability to position oneself in the online environment as real person (Garrison et al., 2000) and to collaborate in the digital world by establishing personal and purposeful

relationships (Garrison, 2007). The main aspects of social presence are the expression of emotions, the open communication and group cohesion in the online format (Garrison et al., 2000).

Teaching presence – mainly referred to the instructor's role – includes firstly the design of educational experiences, i.e. organization of the course as well as design of learning activities and assessment formats. Secondly, teacher presence involves a facilitation function during the lesson (ibid.). Thirdly, direct instruction is considered to be a part of the teaching presence (Garrison, 2007). All three functions of teacher presence focus on the goal "to support and enhance social and cognitive presence for the purpose of realizing educational outcomes" (Garrison et al., 2000, p. 90).

Viewing educational experiences as the result of successful interplay between all three elements, CoI assumes that knowledge construction in online settings depends on the ability of instructors and learners to create forms of perceived presence despite spatial separation (Shea & Bidjerano, 2009).

Online Learning

According to Allen and Seaman (2013), online learning can be defined as a course that is mostly or entirely delivered online, so that typically no face-to-face meetings are conducted. From an e-pedagogical perspective, three different instructor roles can be taken in online environments: Teachers can firstly act as excessively active leaders of students' learning progress or secondly be in a reactive position as facilitators which only respond to students' questions. Thirdly, and preferably, they take the position of a reasonably active mediator, i.e., instructors engage and interact without directly guiding students' learning progress (Serdyukov, 2015).

Even though online learning is from its origin an independent and self-determined process, the need of critical support for the online learner is highlighted in e-pedagogy. To address the demand of social interaction, four forms of organization can be identified: interaction can be enabled by both, text-based and video-based communication, either in synchronous or in an asynchronous setting (ibid.).

Principles for Online Instruction

The value of social interaction for online teaching is also highlighted by Sorensen and Baylen (2009) who adapted the *principles for good practice* of Chickering and Gamson (1987) to online instruction settings. The seven principles for teaching in online environments can be summarized as follows:

1. Enabling student-teacher interaction
2. Facilitating cooperation among students
3. Empowering active learning
4. Providing prompt feedback
5. Managing time on task
6. Communicating high expectations
7. Respecting diverse ways of learning

As shown by Fiock`s (2020) literature review on empirical studies about instructional strategies in online communities, the three core elements of CoI can be related to each of the seven principles. Consequently, the seven principles can be seen as a starting point for implementing instructional activities which consider the CoI model in school praxis (ibid.). In this paper, we understand the seven principles of online instruction as design principles for the creation of educational online environments in line with CoI.

Mobile Learning

Mobile learning can be defined as learning progress facilitated by the use of mobile devices, such as smartphones. Characteristics are the portability of devices as well as their possibilities for communication and interactive representations (Kearney et al., 2020). In a meta-study, Sung et al. (2015) report a positive mean effect of using mobile device on students' learning. The authors emphasize learning environments that offer broad functionalities including authoring tools for teachers to flexibly adapt the system to their own instruction (ibid.).

Mobile apps can promote students' learning progress in numerous mathematical areas, e.g., arithmetic and geometry. Further, the use of apps in math class can foster problem solving strategies or mathematical programming skills. Additionally, the embedding of mobile learning in math education tends to have a positive influence on students' motivation and enjoyment (Drigas & Pappas, 2015).

State of the Art: Mathematics Education in Covid-19 Pandemic

Due to the Covid-19 pandemic, abrupt changes of instruction were needed to deal with the crises circumstances. Within only a few days, new teaching practices were rapidly established (Hodges et al., 2020) mostly by the help of digital media and internet-based communication (Crompton et al., 2021). This temporary shift without appropriate time for designing online teaching courses is described as Emergency Remote Teaching (ERT) (Hodges et al., 2020). Hereby, several challenges concerning mathematics education are reported from a teacher's point of view:

Empirical cross-national research highlights the issue of assessment. Concerning the formative assessment, teachers reported problems in diagnosis as well as individual feedback and support (Aldon et al., 2021; Barlovits et al., 2021; Drijvers et al., in press). During distance education in Spring 2020, instructors mainly focused on procedural skills rather than conceptual understanding (Drijvers et al., in press). In addition, teachers reported difficulties in finding adequate forms of summative assessment (Aldon et al., 2021).

Furthermore, it arouses the question of how to implement inclusive distance education in which students can participate at their individual achievement level (Aldon et al., 2021), especially underachieving students (Barlovits et al., 2021). In addition, teachers reported a lowering of the course level through an increased rate of standard and reproduction math tasks (ibid., Aldon et al., 2021) and an infrequent use of modeling or reasoning tasks (Drijvers et al., in press).

Also, social factors are emphasized in research on mathematical distance education during the ERT phase. Here, the interaction between teacher and student (Aldon et al., 2021; Barlovits et al., 2021) as well as among students, e.g., in form of peer instruction (Drijvers et al., in press), is perceived as challenging. The general ability of fruitful content-related social interaction in math class seems to be dependent on the ratio of synchronous distance education (ibid.)

Moreover, with regard to the finding that teachers paid more attention to the use of general tools, such as video conferencing systems, than on the use of tools designed for math education (Barlovits et al., 2021; Drijvers et al., in press), the availability of technical equipment and the handling of accessible tools must be taken into consideration in the context of distance education (Barlovits et al., 2021).

From the outlined empirical studies, we derive four requirements for digital tools in math distance education during Covid-19 pandemic. An appropriate digital tool in math education has to (i) enable appropriate formative assessment, (ii) promote inclusive forms of teaching and foster different performance levels, (iii) address the issue of social relatedness and (iv) follow a low-barrier approach concerning technical requirements. Being aware that only a few challenges that arose due to crisis situations are presented here, these four design requirements are considered in the following analysis.

Theory-based Design of a Mathematics Online Environment

Mathematical learning in fully online learning environments differs substantially from traditional classroom instruction since it involves a greater amount of asynchronous and self-directed instruction and a lower degree of collaborative work (Choi & Walters, 2018). However, following CoI and the seven principles for online instruction, the opportunity for a teacher-learner interaction and the student collaboration is clearly emphasized. Following the assumption that ability of successful social interaction in math class depends on the number of synchronous lessons (Drijvers et al., in press), online environments should enable *synchronous distance learning*, *direct interaction* and *collaboration* in mathematics distance learning.

Both, the seven design principles as well as the challenges of Covid-19 math distance education, underline the importance of *immediate feedback* and *adaptive design* of learning environments to support and challenge learners at their individual level. Concerning the lack of technical equipment or challenges in its handling (Barlovits et al., 2021), a *mobile learning* approach seems promising due to the high rate of smartphone ownership in Europe and worldwide. Regarding the instructor role, online environments should enable the teacher to act as a *mediator* (Serdyukov, 2015).

The ASYMPTOTE Concept

Based on these considerations, the ASYMPTOTE[1] project is presented as one example for the development of a synchronous mobile environment in the context of the Covid-19 pandemic.

The project aims at the development of a cost-free, open-accessible and low-barrier tool for mobile distance learning in mathematics education. Due to availability and handling of the environment, it is designed for smartphones and tablets. In order to set up this tool for distance mathematics education in a reasonable time, the already existing MathCityMap system (Ludwig & Jablonski, 2019) will be adapted to the needs of online education. The stand-alone system ASYMPTOTE will be available at the beginning of 2023. In the following, the features of MathCityMap are evaluated in light of the theoretical considerations for online instruction. Subsequently, based on the theoretical framework, steps for the further development of ASYMPTOTE are identified.

The MathCityMap System

The MathCityMap system – developed for mathematics outdoor education using the math trail method – consists of two components, namely a web portal for teachers and smartphone app as

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[1] Adaptive Synchronous Mathematics Learning Paths for Online Teaching in Europe. Erasmus+ Strategic Partnership; co-funded by the European Union from 03/2021 to 02/2023 (grant no. 2020-1-DE01-KA226-HE-005738).

working space for students (Gurjanow et al., 2019). In the MathCityMap app, students can easily download samples of tasks via code. The app displays the tasks (Figure 1, left; here: task for distance education), shows up to three hints during and a sample solution after the task solving process on demand. Further, an immediate answer validation in form of a systemic feedback is implemented.

Besides these asynchronous features, the web portal offers teachers within the Digital Classroom the possibility for a real-time monitoring of the students' working progress on both, class and individual level. In addition, a chat function is implemented for a one-to-one synchronous communication between instructor and student (Figure 1, center right and right).

By using MathCityMap in the context of distance education, students work on digital learning paths, i.e., internet-based task sequences to be completed independently at their own performance level with the help of hints and result checks (Roth, 2015). Different answer formats such as values or vectors, cloze texts, or multiple-choice selection are available for task creation. For a detailed description of how the MathCityMap system has been adapted for distance education, see Larmann et al. (2021).

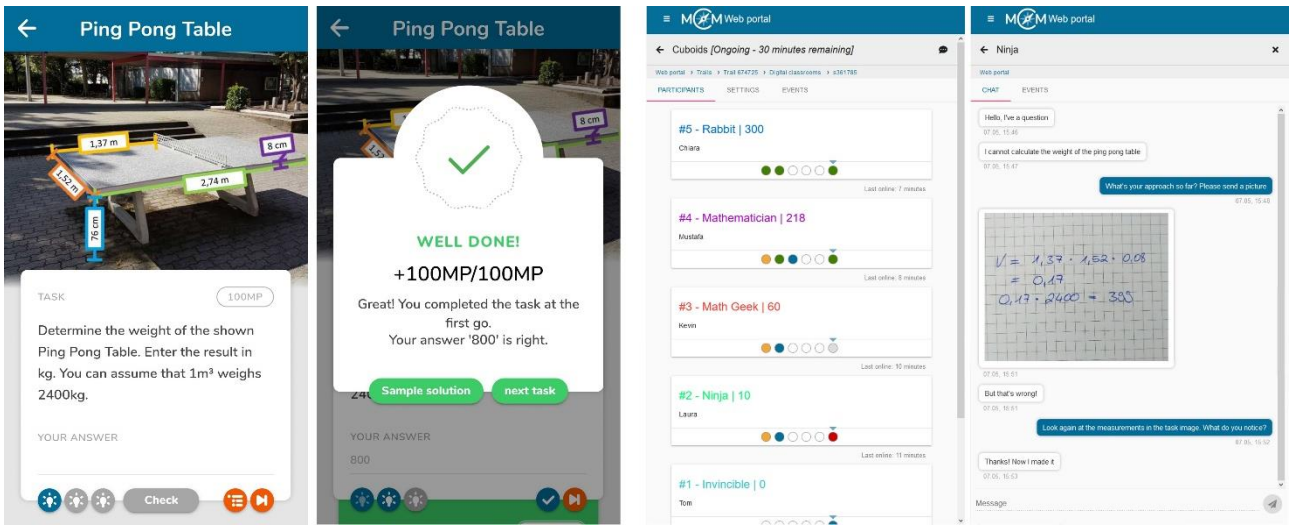

Figure 1: MathCityMap used for distance education from the student's perspective (app; left) and the teacher's view (Digital Classroom in the web portal; right)

From MathCityMap to ASYMPTOTE

Following the considerations for math education online environments, we evaluate the present status of MathCityMap and derive steps of further developments for ASYMPTOTE.

Features of MathCityMap based in line with the identified design requirements: As for *student-teacher interaction*, the chat function of the Digital Classroom provides a possibility for a dialogue between the instruction and the student. Therefore, shown by Larmann et al. (2021), students often start the communication with the teacher to receive feedback on their solution process. Further, teachers can send messages to the whole learning group.

The system provides *prompt feedback*: the student's numerical or text input is immediately validated by the system (Figure 1, center left). In addition, the possibility to send images and audio messages via chat allows teachers to provide individualized support to the student in the sense of formative assessment. Since the systemic feedback distinguishes between correct and incorrect solutions,

instructors gain more time to analyze solutions. Thus, the interplay of systemic and individual feedback follows the idea of semi-automated feedback (Fest, 2011).

For student's *time on tasks*, Sorensen and Baylen (2009) highlight well-structured and -planned lessons as well as the value of teacher's time management. Within MathCityMap, a structured setting by using digital learning paths is provided on which students work in a predefined time slot synchronously. Within the Digital Classroom, instructors can monitor student's individual working progress, track student's engagement and directly contact students via chat if needed. With the monitoring function of the Digital Classroom and the semi-automated feedback, the MathCityMap system seems to address the need of mathematical distance education for formative assessment.

To further encourage the student's *time on task* and to *respect mutual ways of learning*, the system offers the ability for teachers to select available digital learning paths or to create own digital learning paths related to the individual needs of their class. Thus, according to Sung et al. (2015), it provides teachers the ability to make adaptations needed for their own classes. Additionally, MathCityMap enables the structuring of complex tasks in manageable subtasks. While upper-performing students can work on the task at a whole, under-archiving students can be guided through the solution process by the subtasks. Also, the online learning setting itself (Serdyukov, 2015) as well as the concept of digital learning paths (Roth, 2015) respect different paces of learning and levels of performance.

Further developments for ASYMPTOTE based on identified design requirements: Within the ASYMPTOTE project, the possibility to create adaptive learning paths will be developed. Following the idea of decision trees, teachers will be able to define so-called status indicator tasks. Depending on the quality of learner's solution, the app will allocate the next task according to the student's performance. Through the definition of several indicator tasks, the content level of the digital learning path can be more and more adapted to the individual level of the student. Moreover, to facilitate learning for students with disability, a read-out-loud mode and a zoom function will be implemented. Tasks, which are formulated in easy language, will be specially marked. Also, tasks will be translatable in various language which might help to bridge language barriers.

The *high expectations* in online education can be addressed through the use of challenging mathematical tasks. These addresses in particular the focus on standard and reproduction math tasks (Aldon et al., 2021; Barlovits et al., 2021) and the infrequent use of modeling or reasoning tasks (Drijvers et al., in press). Within the ASYMPTOTE project, a broad database of open-accessible tasks and learning paths from lower secondary to university level will be created with a special focus on modeling, problem solving and reasoning tasks.

For enabling *communication* and *collaboration* between students in line with CoI and addressing the issue of students' social relatedness in math class, a teamwork mode will be developed. This involves setting up a group chat for synchronous and text-based interaction (Serdyukov, 2015) to support collaborative task processing, discussion and reflection. Whether this type of interaction is sufficient, of course, will depend on the embedding of the lesson conducted with the ASYMPTOTE system. The authors suggest a joint preparation phase and a post-discussion via video call.

Active learning will be fostered by the ASYMPTOTE system by the provision of complex tasks on a variety of topics from lower secondary to university level as well as the teamwork mode. Since

ASYMPTOTE can be considered as an adaptive tutoring system, however, active learning is not additionally promoted by manipulative and interactive tasks: the system does not provide an integrated dynamic geometry software or computer algebra functionalities.

Conclusion

This paper presents a theoretical framework for mobile learning environments aiming at distance mathematics education. It is referred to the Community of Inquiry model, e-learning and online teaching practices as well as mobile learning. Based on the theoretical considerations, design requirements for distance learning systems for mathematics education are developed – also in line with reported challenges of distance mathematics education during Covid-19 pandemic.

Furthermore, the ASYMPTOTE system is introduced, with technical development scheduled to be completed by the beginning of 2022. The system is characterized by an adaptive, synchronous and mobile learning setting. Based on the theoretical framework, we evaluate the present status of ASYMPTOTE and identify needed demands of further developments. Due to the theory-based development of ASYMPTOTE, the mathematics online environment can be considered as a promising tool for mathematics distance education. Thus, we expect that the system will make a substantial contribution to the improvement of online instruction in math class. To which extend the system addresses the issue of social presence in online environments (CoI) and how it affects teachers' and students' perception of the distance situation, has to be investigated by future research.

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