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► To cite this version:

Simon Barlovits, Matthias Ludwig, Georgios Fesakis, Alexandra Kolokytha. Designing mobile environments for mathematics distance education: The theory-driven development of the ASYMPTOTE system. Twelfth Congress of the European Society for Research in Mathematics Education (CERME12), Free University of Bozen-Bolzano; European Society for Research in Mathematics Education (ERME), Feb 2022, Bozen-Bolzano, Italy. hal-03747390v1

HAL Id: hal-03747390

<https://hal.science/hal-03747390v1>

Submitted on 8 Aug 2022 (v1), last revised 19 Nov 2022 (v2)

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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. Emerged ways of instruction – 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 reported challenges of mathematics distance education, 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, e-pedagogy, and mobile learning to deduce design requirements. Secondly, the ASYMPTOTE project is introduced as an example for mobile mathematics education at a distance. Based on the discussed Covid-19 experiences and the derived design requirements, the present status of the ASYMPTOTE system is evaluated. In addition, necessary further developments of the system are identified.

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

Introduction: Mathematics Education in Covid-19 Pandemic

Due to the Covid-19 pandemic, abrupt changes of instruction were needed to deal with the crisis. 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 highlighted the issue of assessment during Covid-19-induced distance education. 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., 2021). In Spring 2020, instructors mainly focused on teaching procedural skills rather than conceptual understanding (Drijvers et al., 2021). In addition, teachers reported difficulties in finding adequate forms of summative assessment (Aldon et al., 2021).

Furthermore, the question arose of how to implement inclusive distance education in which students can participate at their individual achievement level (Aldon et al., 2021). In addition, teachers reported an increased rate of standard and reproduction mathematical tasks (Aldon et al., 2021, Barlovits et al., 2021) and an infrequent use of modeling or reasoning tasks (Drijvers et al., 2021).

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., 2021), is perceived as

challenging. The general ability of fruitful content-related social interaction in math class seemed to be dependent on the ratio of synchronous distance education (Drijvers et al., 2021)

Moreover, teachers paid more attention to the use of general tools such as video conferencing systems than on the use of tools designed for mathematics education (Barlovits et al., 2021; Drijvers et al., 2021). Because this may be due to the availability of technical devices and the handling of accessible tools (Barlovits et al., 2021), this issue should be considered within distance education.

From the outlined empirical studies, we derive four demands for digital tools in mathematics distance education. An appropriate digital tool in mathematics 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. To address the demands (i)-(iii), the Community of Inquiry model (CoI) and principles of online learning are subsequently introduced. In addition, mobile learning is taken into consideration to meet demand (iv). Being aware that only a few challenges that arose due to crisis situations are presented here, these four demands are chosen to derive design requirements for mathematics distance learning environments in the following.

Theoretical Framework

Community of Inquiry

A well-known approach for the design of digital educational environments is the Community of Inquiry model (CoI), which emphasizes 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 defined “as the exploration, construction, resolution and confirmation of understanding through collaboration and reflection in a community of inquiry” (Garrison, 2007, p. 65). It 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 in the creation of new concepts. Afterwards, the skills and knowledge acquired are practiced in real situations (Garrison et al., 2000).

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 learning activities and assessment formats. Secondly, teacher presence involves a facilitation function during the lesson (Garrison et al., 2000). 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).

Online Learning and Principles for Online Instruction

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 its origin, it can be considered as an independent and self-determined process. However, in line with CoI, the need of social relatedness, communication, and collaboration for online learning is also highlighted (Serdyukov, 2015). To foster student's interaction and to fulfill the need of critical support online instructors should preferably take the position of a mediator: They engage and interact without directly guiding students' learning progress (Serdyukov, 2015).

The value of social interaction for online teaching is also emphasized by the seven principles for teaching in online environments (Sorensen & Baylen, 2009), which 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 (2020), all three core elements of CoI can be related to each of the seven principles, i.e., each principle includes aspects of social, cognitive and teaching presence. Consequently, the seven principles can be seen as guidelines for implementing instructional activities in school praxis which consider the CoI model (Fiock, 2020.). In this paper, we understand the seven principles of online instruction by Sorensen & Baylen (2009) as operationalization to create educational online environments in line with CoI.

Mobile Learning

Mobile learning can be defined as learning progress facilitated using 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).

According to the meta-study by Sung et al. (2016), a positive effect of using mobile device on students' mathematics learning can be assumed. Additionally, embedding mobile learning in mathematics education tends to have a positive influence on students' motivation and enjoyment (Drigas & Pappas, 2015).

Theory-based Design of a Mathematics Distance Learning Environment

Design Requirements

Mathematical learning in fully online learning environments differs substantially from traditional classroom instruction since it usually involves a greater amount of asynchronous and self-directed instruction as well as a lower degree of collaborative work (Choi & Walters, 2018). However, the Covid-19 pandemic clearly showed the issue of social relatedness. Social presence in the CoI model as well as the 1st and 2nd principle for online instruction strongly emphasize the need for teacher-learner interaction and student collaboration. Following the assumption that the ability of successful social interaction in distance math class depends on the number of synchronous lessons (Drijvers et

al., 2021), online environments should enable *synchronous distance learning*, *direct interaction* and *collaboration*. Regarding the instructor role, mathematics distance learning environments should enable the teacher to act as a *mediator*, i.e., to take a balanced role between fully student-centered learning and strongly teacher-guided learning (Serdyukov, 2015).

Furthermore, the needs of appropriate formative assessment, inclusive forms of teaching and addressing different performance levels were derived from the experience of Covid-19 distance education. This can be found in particular in the 4th and 7th principle for online instruction. Both, the principles as well as the challenges of Covid-19 mathematics distance education, underline the importance of *immediate feedback* and *adaptive design* of learning environments to support and challenge learners at their individual levels. Concerning the lack of technical equipment or challenges in its handling, a *mobile learning* approach seems promising due to the high rate of smartphone ownership in Europe and worldwide.

The ASYMPTOTE Concept

Based on these design requirements, the ASYMPTOTE¹ 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-tech barrier tool for mobile distance learning in math class. 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 concerning the seven principles of online instruction and the derived design requirements. 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 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 an evaluative feedback based on student's input (well done/ok/wrong) is implemented.

Besides these asynchronous features, the web portal offers teachers within the so-called feature 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).

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).

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, fill in the blanks, 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).

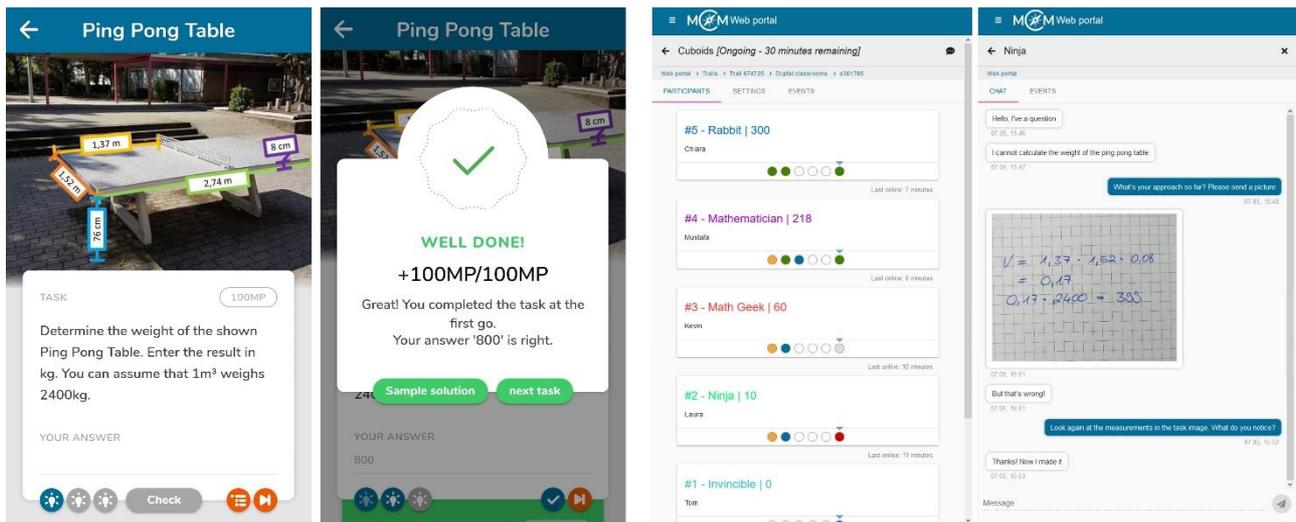


Figure 1: MathCityMap used for distance education from the student's perspective (app; left) and the teacher's view (Digital Classroom in the web portal; right)

From MathCityMap to ASYMPOTOTE

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

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 according to 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 higher-attaining students can work on the task at a whole, lower-attaining 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 tasks can be more and more adapted to the individual level of the student – the linear learning path of MathCityMap is changed to an individualized learning graph within the ASYMPTOTE system.²

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.

To enable *communication* and *collaboration* among students in line with CoI and to address the issue of students' social relatedness, a teamwork mode will be developed. Following the low-tech barrier approach, a chat for sending text, image or audio messages is chosen to work on collaborative tasks. However, because a chat only offers a limited space for students' interaction and discussion, the appropriateness of this interaction channel depends on the embedding of the lesson conducted with ASYMPTOTE. The authors suggest a joint preparation phase and a post-discussion via video call.

The principles *high expectations* and *active learning* in online education can be addressed by challenging mathematical tasks. These addresses in particular the focus on standard and reproduction tasks (Aldon et al., 2021; Barlovits et al., 2021) and the infrequent use of modeling or reasoning tasks (Drijvers et al., 2021). 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. Since the integration of a dynamic geometry software into ASYMPTOTE is planned, manipulative and interactive tasks will be possible in future. In addition, *active learning* can be fostered by student's collaboration within the teamwork mode.

² The adaptivity will also be incorporated into the future representation of the Digital Classroom (current state: Figure 1, right-hand side): At the individual level, the students' work process will be represented by the adaptively assigned tasks. At the class level, the systemic overview of how students solved the tasks will be extended. Thus, ASYMPTOTE system aims to address the challenge of diagnosis and individual support during Covid-19 distance learning.

Conclusion

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

In addition, the ASYMPTOTE project is introduced as an example for distance learning systems in mathematics education. The system is characterized by an adaptive, synchronous and mobile learning setting. Its technical development is scheduled to be completed in Spring 2022. 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 learning 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 what extent 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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