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Distance learning versus face-to-face classroom learning: student achievement in conditional probability when using a digital textbook with integrated digital tools

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The COVID-19 pandemic has had an impact on learning and teaching mathematics in many countries. In Germany, as in other countries, the measure of distance learning was taken. We consider the use of digital mathematics textbooks with integrated digital tools to be particularly suitable for remote or distance learning. The potentials of digital mathematics textbooks, such as assessment, interactivity or collaboration possibilities address the challenges teachers faced in distance learning. Whether mathematical learning processes can also be initiated among students during distance learning is investigated in this study using achievement tests. For this purpose, students in distance and classroom learning who have completed the same series of lessons on conditional probability and authentic contexts are compared. Results from the pretest-posttest design are presented.

Keywords: Achievement, digital textbook, digital tools, distance learning, influence of technology.

Introduction

In the project KomNetMath, teachers and their upper secondary mathematics courses in Germany are provided with a digital textbook with integrated digital tools for one school year. The use of the digital textbook is being empirically investigated. One of the main goals of the accompanying study is to investigate the influence on learning and achievement (Brnic & Greefrath, 2021). Of particular interest is the comparison of the use of the digital textbook to the use of analogue printed materials. This is done in the context of a series of lessons on conditional probability in a face-to-face classroom setting. As a result of the COVID-19 pandemic, a study was conducted in which students in a distance classroom setting performed the same series of lessons. Therefore, students who used the same digital materials in the face-to-face and distance classroom settings and received the same tasks and teacher instructions in synchronous learning can be compared. Using a pretest-posttest design, it is possible to measure the extent to which achievement differences occur depending on whether the students completed the series at school or at home using a digital textbook.

The COVID-19 pandemic and its impact on mathematics education

The COVID-19 pandemic has had a major impact on everyday life in many countries, as well as on educational institutions. Lockdowns and social distancing regulations have changed teaching and learning during this period (Engelbrecht et al., 2020). In Germany, for example, parts of the school year in 2020/21 took place in remote or distance learning. In such a teaching setting, the use of technology was crucial (Bakker et al., 2021). Technology could be used, among other purposes, to connect with students via videoconferencing or to work with digital materials, such as a digital textbook. At the same time, the school closures and the different access to technology are seen as

possible causes for a deepening of social gaps (Engelbrecht et al., 2020). The long-term consequences for teaching mathematics and mathematical education are currently being discussed in particular in the editorials of various mathematics education journals (e.g., Cai et al., 2020; Engelbrecht et al., 2020).

First studies on the impact of the COVID-19 pandemic on mathematics teaching focus especially on the teachers' perspective (Aldon et al., 2021; Drijvers et al., 2021). In particular, interaction, communication, and opportunities for in-person feedback are reported to have changed in distance education compared to face-to-face instruction and are associated with greater hurdles (Aldon et al., 2021; Cai et al., 2020). Additionally, for some teachers in Germany, Flanders and the Netherlands the belief was found that distance teaching is more suitable for teaching procedures and algorithms than for teaching authentic and complex mathematical activities (Drijvers et al., 2021). Aldon et al. (2021) identified four challenges for teachers in particular:

(a) managing distance learning to support students' learning through specific methodologies; (b) managing distance learning to develop assessment; (c) managing distance learning to support those students that face difficulties and/or are living a difficult situation/developing inclusive teaching; and (d) managing distance learning to exploit its potentialities for fostering typical mathematical processes. (Aldon et al., 2021, pp. 1, 6)

To what extent these challenges can be overcome in distance learning and how teaching-learning processes can be successfully implemented from the students' point of view, remains to be clarified.

The potential of digital mathematics textbooks

For many teachers, the textbook is the most important resource in the mathematics classroom (Fan et al., 2013; Rezat et al., 2021). Thus, the textbook has a significant influence on classroom instruction (Fan et al., 2013). Due to the importance of the textbook, it can be assumed that this resource was also relied upon in times of the COVID-19 pandemic. The use of digital textbooks exemplifies the use of technology in distance learning. Digital mathematics textbooks may differ significantly from analogue printed mathematics textbooks. The potential of digital mathematics textbooks is visible in various dimensions. Modern digital textbook offers opportunities to interact with the book and with individual tasks (*Interactivity*), but also with other people (*Socialization*). In addition, new adaptation and design options are available (*Customizing the Learning Experience*) and assessment is an integral part of a digital textbook (*Ongoing Assessment and Reporting of Student Progress*). Furthermore, a digital textbook can be updated quicker and continuously (*Potential Economic Benefits of Digital Content*) (Choppin et al., 2014).

Pepin et al. (2015) distinguish three different types of digital mathematics textbooks, which differ in their design or structure as well as in their creation. The "integrative e-textbook" is a digitised version of a traditional, printed textbook. It therefore largely corresponds to the characteristics of analogue printed textbooks. The content is enriched by add-ons and links. In contrast to the integrative e-textbook, the "evolving or 'living' textbook" is not written by a classical authorship, but is continuously developed by a community. The third type corresponds to an "interactive e-textbook". This is a variant that mainly consists of learning objects. These learning objects include tasks and interactive elements. These objects can be linked and connected to each other (Pepin et al., 2015).

However, other types of digital textbooks or learning tools that do not fit into this categorisation are also conceivable (Pepin et al., 2017).

Learning with digital textbooks and its integrated digital tools

The structure and content of a (digital) mathematics textbook have an impact on the learning opportunities a textbook offers, and this can eventually result in an impact on learner performance (Pepin et al., 2015; Sievert et al., 2021). The textbook, as an artefact, is a mediator between the intended curriculum and the teachers' final actions (Fan et al., 2013; Valverde et al., 2002). According to the *didactic tetrahedron model*, the textbook influences the interactions between mathematics, students and teachers (Rezat & Sträßer, 2012).

So far, the use of textbooks and the influence on learners' achievement has only rarely been investigated (Fan et al., 2013). Research comparing digital and analogue materials has shown an initial positive effect of digital materials (Brnic & Greefrath, 2021; Reinhold et al., 2020). It became apparent that certain groups of people could particularly benefit from digital materials, specifically low-achieving students (Reinhold et al., 2020) or – in comparison of gender – female students (Brnic & Greefrath, 2021). With regard to the use of digital tools, meta-studies also found a positive effect on learning outcomes (Hillmayr et al., 2020).

Research Question

Initial study results indicate that digital mathematics textbooks with integrated tools have positive effects on learning compared to analogue materials (Brnic & Greefrath, 2021; Hillmayr et al., 2020; Reinhold et al., 2020). Digital textbooks are particularly characterised by their potentials and interactive features (Choppin et al., 2014; Pepin et al., 2015). These technological potentials precisely address the challenges that teachers face in mathematics lessons in distance learning, e.g. communicating with students or giving feedback (Aldon et al., 2021; Engelbrecht et al., 2020). However, the extent to which learning processes can actually be successfully initiated in a lesson with a digital textbook that also takes up authentic contexts is still a research desideratum. This results in the following research question:

What influence does the use of a digital textbook with integrated tools have on the students' achievement in the context of a series of lessons on conditional probability in distance learning?

This question will be investigated in a comparison with students who have completed the same series of lessons in a face-to-face classroom setting.

Method

The digital mathematics textbook Net-Mathebuch

The digital mathematics textbook Net-Mathebuch (www.m2.net-schulbuch.de) was used for this study. This interactive textbook was designed as a *digital* textbook and is not based on a printed textbook. The book can be used in the sixth form of the Gymnasium in Germany and covers the content relevant for the German Abitur. It is continuously revised and further developed by a group of mathematics teachers. Feedback from other teachers or students is incorporated. It therefore has the characteristics of an "evolving or 'living' textbook" (Pepin et al., 2017). Besides, digital tools are

constantly provided with integrated GeoGebra features, thus fulfilling the characteristics of an “interactive textbook” (Pepin et al., 2017). It takes up several of the theoretical potentials of a digital textbook (Choppin et al., 2014):

Potentials of digital textbooks	Examples from the Net-Mathebuch
Use of Multimedia	Learning videos; animations; simulations; pop-up windows and tool tips; gap texts; slide shows; ...
Interactivity	Interactive tasks, e.g., through GeoGebra apps; tasks with selection options through checkboxes or radio buttons; drag and drop tasks; ...
Socialization	Upload function for own materials; chat; ...
Customizing the Learning Experience	Adaption to individual needs and learning styles, e.g., by setting bookmarks and links; unlocking of solutions by the teacher; ...
Ongoing Assessment and Reporting of Student Progress	Integration of different types of feedback; print and save option; ...
Potential Economic Benefits of Digital Content	Quick revision possibility of the content and features of a digital textbook by the editors; integration of current contexts; ...

Figure 1: Potentials of digital textbooks with examples from the Net-Mathebuch

Sample and data collection

As part of the KomNetMath project, teachers and their students are provided with the digital mathematics textbook Net-Mathebuch free of charge for one school year. Teachers participating in the project receive regular in-service training to support the use of the textbook in the classroom. By participating in the project, the teachers agree that they and their students will take part in an accompanying study. In the study, different mathematics didactic questions are investigated, e.g. the influence of the use of a digital textbook on computer-specific self-efficacy expectations and the comparison between the use of a digital textbook and analogue printed materials (Brnic & Greefrath, 2021).

In the study presented here, 12 upper secondary mathematics courses (year 10 and 11) participated. The average age of the students was $M = 15.62$ ($SD = .69$). The five-hour series of lessons on conditional probability was conducted by 87 (39 female) students in September/October 2020 in face-to-face classroom settings and in April/May 2021 63 (28 female) students in distance learning. The distance learning students were home-schooled at this time due to the pandemic and a nationwide lockdown. The lessons were taught using the Microsoft Teams video conferencing system. The mathematics lessons took place regularly according to the timetable. In the video conferences, the students and teachers were online for the entire time. In the distance and face-to-face lessons, the pre- and posttest as well as the series of lessons were conducted synchronously in the respective courses. In both research groups the students always received the same instructions so that they worked on the same tasks in the same order in the series of lessons.

Design of the intervention and test instrument

A lesson series on conditional probability was developed for the KomNetMath project. In this five-hour lesson series students work on tasks from the Net-Mathebuch. Most of the tasks deal with authentic contexts, for example a home HIV test and DNA analysis. The lesson series is to be carried out according to predefined course plans for the individual lessons. In order to minimise the influence of the teacher, the students should mainly work on their own. The students can check their own solutions for some tasks with feedback options in the digital textbook independently (see Figure 2).

Aufgabe 9

Die folgende Vierfeldertafel bezieht sich auf Menschen mit einem Internetzugang in Deutschland und einer Untersuchung zur Nutzung von Social-Media.

	männlich (m)	weiblich (w)	Gesamt
Social-Media-Nutzer*in (SMN)	30 244 123		65 875 703
kein(e) Social-Media-Nutzer*in (KSMN)		4 403 093	
Gesamt	38 774 520		

prüfen löschen lösen

a. Berechnen Sie die fehlenden Felder in der Vierfeldertafel.
 b. Bestimmen Sie $P(m)$ und $P(SMN)$.
 c. Berechnen Sie $P(w | KSMN)$ und $P(KSMN | w)$.
 d. Ordnen Sie die Sprechweisen den entsprechenden Schreibweisen zu.

$P(w KSMN)$		$P(KSMN w)$		$P(m)$		$P(w)$	
$P(w \cap KSMN)$							

Figure 2: Sample task with feedback option for the solution

Before and after the lesson series, the students take a test on conditional probabilities. The test contains a total of 21 items. The pre- and posttest are linked with 5 anchor items so that the students also solve different tasks in both tests and no repetition effects occur. The test is originally designed as a paper-pencil test for face-to-face instruction so that students can draw their own tree diagrams or fourfold tables. For distance learning, the test format was slightly adapted and partially digitised so that the pre- and posttest could be conducted via video conference. In distance learning, the items were made available to the students digitally using the SociSurvey software. The answer options in multiple-choice format and semi-open response format could also be entered directly by the students digitally. Necessary calculations were carried out on a piece of paper as in a paper-pencil test and uploaded. Since the items were only coded dichotomously, a comparable evaluation of the tests was possible between the classroom and digital setting.

The data are scaled using the Conquest software and a Rasch model. Subsequently, person parameters are analysed with evaluation procedures of the classical test theory. A one-parameter and one-dimensional Rasch Model is used for the pretest and posttest (Rasch, 1960; Wu et al., 2007). Two items were excluded from the analysis because they had a discriminatory power of less than 0.2, which is too poor (OECD, 2012). To check the fit of item and model, the weighted mean square fit (WMNSQ) for each item is also considered. The values for the remaining items range between 0.89 and 1.07 and are thus in a suitable range for the discriminatory power (OECD, 2012). The EAP/PV reliability is 0.51, which is a sufficient value for group comparisons (Lienert & Raatz, 1998).

Results

Figure 3 shows the results from the pretest and posttest from both groups. A higher score corresponds to a better result in the pretest or posttest.

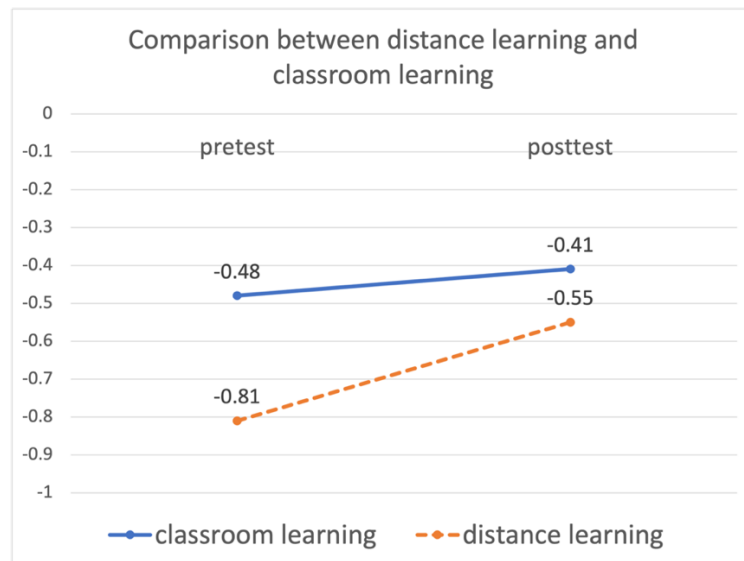


Figure 3: Results of the pretest and posttest on conditional probability

The pretest already portrays that both groups differ significantly with $t(147) = 2.23, p = .027$. The effect size of Cohen's $d = .37$ corresponds to a small effect. A two-way repeated measures ANOVA shows a significant result for the main effect between the measurement time point with $F(1, 147) = 3.96, p = .048, \text{partial } \eta^2 = .03$. This is a small effect. The interaction between the measurement time points and the group reveals no significant effect ($F(1, 147) = 3.96, p = .254, \text{partial } \eta^2 = .01$). The within-subject factor group is not significant with $F(1, 147) = 2.785, p = .097, \text{partial } \eta^2 = .02$. Analyses in both groups show that the face-to-face classroom setting group does not significantly increase with $t(85) = -.73, p = .229$. In contrast, the distance learning group increases significantly from pretest to posttest with $t(62) = -1.82, p = .038$ and a small effect of Cohen's $d = .23$.

Discussion

Although the groups already differ significantly at the first measurement point before the treatment, no interaction between the measurement points and the group can be found. Nor are differences in achievement attributable to the group membership.

The assumption that the students show a gap in distance learning to the students in face-to-face classroom learning seems to be confirmed by this sample. Although they manage to improve significantly, they are still at the level below the face-to-face group after the intervention. Whether these differences can be attributed to the challenges for teachers mentioned above (Aldon et al., 2021; Cai et al., 2020) cannot be answered by this study design. Differences between the groups can also be attributed to the fact that both reference groups were taught by different teachers.

The results give indications that the students in distance learning were even able to benefit comparatively more from the digital textbooks and its integrated tools than in face-to-face learning. The digital textbook seems to have particular potential in distance learning and the results indicate

that especially low-achieving students from the pre-test benefit particularly from interactive materials (Reinhold et al., 2020). Which potentials and digital tools or in which areas of the tests the respective groups could particularly benefit from requires additional in-depth analyses. Further analyses can also examine whether multidimensional Rasch models can be used or whether a more differentiated analysis of student solutions is possible. Nevertheless, the study shows that students can also learn to deal with complex mathematical content in distance learning. A prerequisite in this study was that the lessons take place synchronously and all students have access to the technology. Nevertheless, it was also observed during the course of the lessons that technical problems can occur occasionally, making communication, for example, more difficult.

The results show that across the entire sample, students were able to improve their performance. This is consistent with other studies that have also found positive effects of digital tools (Hillmayr et al., 2020). In this project, we will further investigate to what extent achievement differs from the use of analogue materials and to what extent students benefit from the potentials of digital mathematics textbooks.

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