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BYOD vs pool: Effects on competence development and cognitive load

Maurice Krause, Gilbert Greefrath, Cornelia Denz, Susanne Heinicke,
Stefan Heusler, Robin Janzik, Bianca Kramp, Fabienne E. Kremer,
Daniel Laumann, Barbara Leibrock, Annette Marohn, Dörthe Masemann,
Thorsten Quandt, Felix Reer, Elmar Souvignier and Malte Ubben

University of Münster, Germany;

{maurice.krause, greefrath, denz, susanne.heinicke, stefan.heusler, robin.janzik,
bianca.kramp, fkremer, daniel.laumann, barbara.leibrock, a.marohn, d.masemann,
thorsten.quandt, felix.reer, elmar.souvignier, malte.ubben}@uni-muenster.de

In this article, we investigated differences in the effects of student-owned smartphones (BYOD) and provided smartphones (pool) on mathematics modeling competence development and cognitive load. Therefore, we conducted an intervention study, used a Rasch model and applied a mixed model ANOVA to investigate the competence development ($n = 176$) as well as a Mann-Whitney U test to investigate the cognitive load ($n = 186$). We showed that there is no significant difference between the two treatment groups in terms of their competence development ($p = .876$). For cognitive load, we showed for one task that learners in the BYOD group were significantly less cognitively loaded than learners in the pool group ($p = .047$) and no significant differences for four other tasks ($.08 \leq p \leq .579$).

Keywords: Handheld devices, technology planning, influence of technology.

Introduction

An essential question when using digital media and tools in the classroom is with which device the students should access the digital materials. In addition to the question of the device type (e.g., desktop computer, laptop, tablet, smartphone, ...), it is also relevant whether students' own devices or school devices should be used—although it does not seem logistically sensible for all device types (e.g., desktop computers) to have students bring them to school. The question does not become clearer if one takes into account that different variants of the two possibilities mentioned exist, which differ, for example, in terms of the concrete design of the variables ownership, device management and device availability. Furthermore, differences arise from the device provisioning concepts, for example in the distraction potential of the devices or in the student motivation. In addition to the great uncertainty, this question also has great significance for school learning. In the study presented here, the two provisioning concepts BYOD (“bring your own device”) and pool are compared with each other in terms of competence development and the directly connected cognitive load perceived by students when working either with their own devices or with provided devices.

Theoretical Background

Device Provisioning Concepts

Any use of digital media requires access to a suitable digital device. There is a wide range of concepts for the provision of mobile devices such as laptops, tablets or smartphones. In the school context, most commonly the concepts of *BYOD*, *GYOD*, *COPE* and *pool* are used (see Table 1). Under the

BYOD (“bring your own device”) concept, students' private devices are used at school. Also, under the GYOD (“get your own device”) concept, private devices are used at school, but the school limits more or less precisely which devices may be purchased by the students, thus reducing or eliminating device heterogeneity in the classroom. Under the COPE (“corporate owned, personally enabled”) concept, learners are given school-owned devices to use on a long-term basis. Whereas in the concepts mentioned so far the devices are available to the students outside of class time and can thus also be used, for example, when working on homework, this is generally not possible under the pool concept. Within this concept, the school acquires a pool of devices—often several class sets—and usually only issues them to the students for short-term use during class time.

Table 1: Characteristics of Different Device Provisioning Concepts

Device provisioning concept	Device owner and cost bearer	Device selection	Device management	Device availability
BYOD ^a	Student	Student	Student	In and out of class
GYOD ^b	Student	Preselection or full selection by school	Student	In and out of class
COPE ^c	School	School	Student and school	In and out of class
Pool ^d	School	School	School	In class

Note. The most common realizations of the four device provisioning concepts are given. Some of the stated realizations are not unambiguous, but may vary slightly.

^a Acronym for “bring your own device”. ^b Acronym for “get your own device”. ^c Acronym for “corporate owned, personally enabled”. ^d Short for *device pool*.

The differing characteristics result in further potentially learning-relevant consequences between the concepts. On the one hand, digital devices have a certain potential for distraction (Karsenti & Fievez, 2013), which may also increase with greater possibilities for individualization and inhibits the growth of competencies. In contrast, however, students are more motivated when digital devices are used for learning (Burden et al., 2012). This motivation may vary depending on ownership or individualization opportunities.

Cognitive Load

According to the multi-store model of memory, a limiting factor for learning is the finite capacity of working memory (Atkinson & Shiffrin, 1968). However, this memory is stressed by different types of cognitive load during learning. Specifically, three types of cognitive load can be distinguished that affect learners: intrinsic cognitive load, extraneous cognitive load and germane cognitive load (Sweller, 1988). While intrinsic load is dependent on the complexity of the learning object, extraneous load is influenced by the external learning conditions. Whereas germane load is considered as positive cognitive load and is defined by the actual learning processes. Successful

learning is achieved when the total cognitive load does not exceed the capacity of the working memory.

In a study of 520 smartphone users, Ward et al. (2017) showed that the mere presence of one's own smartphone causes cognitive load. Study participants who had their smartphone on the table during a corresponding test showed significantly worse results in the area of available cognitive capacity than participants who stored their smartphone outside the test room. Whether provided smartphones cause similar effects was not investigated in this study. In contrast, however, students' familiarity with their own device can be assumed to reduce the cognitive load in the BYOD concept (cf. Welsh et al., 2018).

Mathematical Modeling

Mathematical modeling is one of six general mathematical competencies of the German educational standards (see Sekretariat der Ständigen Konferenz der Kultusminister der Länder in der Bundesrepublik Deutschland, 2004) and allows for a diverse use of digital tools (Greefrath et al., 2018).

Research Questions and Hypotheses

Since in school currently different concepts for the provision of digital devices are practiced, the question arises whether these concepts have different effects on the competence development of the students. In view of the shown effects of the presence of one's own smartphone on cognitive load, a further question arises as to what extent the smartphone-caused cognitive load differs between different provisioning concepts when the smartphones are actively used. Specifically, the following questions are investigated and the related hypotheses are tested:

- | | |
|-----|---|
| RQ1 | Is there a difference in effects on mathematical modeling competence development between the BYOD and pool concept? |
| RQ2 | To what extent does the cognitive load of a task differ between the BYOD and pool concept? |
| H1 | The mathematical modeling competence develops differently between students taught under application of the BYOD concept and those taught under application of the pool concept. |
| H2 | The cognitive load of a task differs between students taught under application of the BYOD concept and those taught under application of the pool concept. |

Method

The comparison of the two device-type-independent provisioning concepts BYOD and pool has been carried out in this study using smartphones as an exemplarily device. The main reason for this is that the BYOD concept requires that students already have their own devices of the corresponding type. In order to not make the schools' participation in the study dependent on whether or not they have a device pool (of smartphones), the students in the pool group received university smartphones that were configured in a school-like manner. For example, students were not able to install apps on their own. Since it can be assumed that an established pool concept tends to cause fewer operating difficulties for the students than using an unfamiliar operating system, pool devices with the Android and iOS operating systems have been purchased and handed out according to the operating system used by the students privately.

The Project *smart for science*

This study is part of the research project *smart for science*, which investigates how student-owned smartphones (BYOD) can be successfully integrated into school classes. For this, the project offers workshops in the subjects of mathematics, physics and chemistry on the topic of electromobility for lower secondary school classes. During these workshops, qualitative data, namely videos from students' perspective, is recorded as well as a variety of variables is collected quantitatively. This data is complemented by further general data, collected at an additional date prior to the workshops.

Sample and Data Collection

In total, 234 students participated in the mathematics workshops between November 2020 and October 2021. The study sample is a convenience sample at the class level. The sample was formed through requests for participation made to school teachers or through self-selection by teachers. However, individual students were able to opt out of data collection and thus participation in the workshop. The assignment of the students to one of the two experimental groups was randomized at the individual level.

As for two classes the workshop realization differed from the manual, these classes had to be excluded from the analysis. Furthermore, some single students had to be excluded as well, as they showed up late, had to leave early or had to leave inbetween. Moreover, for analysis of the modeling competence development 10 further students had to be excluded from the analysis, as they did not participate in the posttest or swapped their assigned posttest with their seatmate. This leads to a sample size of 186 students ($M_{age} = 13.98$, $SD_{age} = 0.69$; 88 female, 70 male, 4 non-binary) for cognitive load analysis and 176 students ($M_{age} = 13.97$, $SD_{age} = 0.69$; 83 female, 67 male, 3 non-binary) for modeling competence development analysis. The students are distributed among nine classes of grades 8 and 9 in four secondary schools from North Rhine-Westphalia, Germany.

Quantitative Study Design

Prior to attending the workshops, students completed two general quantitative questionnaires once at a preceding meeting to collect background data. Study participants were then randomly assigned at the person level to one of the two study groups, BYOD or pool. The students then attended one, two or all three of the aforementioned workshops. The two study groups were each taught in parallel by a trained project staff member.

The data collection during the mathematics workshop days have been roughly structured as follows: First, a 15-minute organizational phase, a 10-minute questionnaire and a 15-minute competence-based performance test have taken place. Then, the intervention of approximately 3:00 hours has been conducted. During this intervention, students have completed a short questionnaire after completing tasks 1, 2, 3, 5 and 8 that measured, among other things, cognitive load. Further, during task 8, students have participated in a concentration test. Finally, again a 15-minute competence-based performance test has been conducted.

The restriction and selection of the tasks to measure cognitive load took place in order not to overload the students and at the same time to get an impression of possible differences between diverse tasks. For an insight in the tasks see the following section.

Intervention

During the learning time of the mathematics workshop, students completed eight mandatory and two optional tasks (no. 9 and 10) in the area of mathematical models describing the relationship between the mileage of an electric car and the emissions of climate-changing greenhouse gases it causes.

As an introduction to the workshop, in task 1 the students watched and worked through an interactive explanatory video with quiz questions embedded using H5P. These were multiple-choice questions or a drag-and-drop cloze. In task 2, students used a CO_{2eq} calculator to determine the related CO_{2eq} emissions caused in eight life domains based on a given person description. Then, in task 3, students used a bar chart applet to visualize the determined values, created a screenshot, and shared it with the class on a digital collaborative bulletin board. In task 4, only minimal smartphone use took place when writing down the determined values of the mobility life domain (cf. task 2) analogously. In task 5, the students first used the familiar CO_{2eq} calculator as a simulator to generate data pairs of distance driven and CO_{2eq} emissions caused, and then a multi-representation system to visualize the previously obtained table of values in a coordinate system and to determine a regression line using two sliders (one each for slope and y-axis intercept). In task 6, students interpreted the regression line in the factual context; little or no smartphone use occurred here. In task 7, students used the smartphone as a function plotter to graphically determine intersections and potentially as a calculator beforehand. Task 8 allowed the students to use the smartphone in a variety of ways, especially for research on the World Wide Web and also as a calculator or function plotter.

Modeling Competence Instrument

To record the students' modeling competence before and after the workshop, a competence-based performance test was used. In total, there is a pool of 16 items, which are based on items of the Institut zur Qualitätsentwicklung im Bildungswesen (n.d.), developed for the German comparative test in grade 8 (VERA-8) and were used in prior years. All 16 items measure the competence *mathematical modeling* within the core theme *functional relations*. From these, four test versions with 8 items each were created. Since the data collected will be used to explore a possible effect of the digital device, the pre- and posttest were paper-based without the use of the smartphone.

Cognitive Load Instrument

To measure task-related cognitive load, the learners rated the item "How easy or difficult was it for you to complete the task?" on a 9-point Likert scale ranging from "very very easy" to "very very difficult" after completing the respective task. This instrument is adopted from Kalyuga et al. (1999).

Data Analysis

To answer research question RQ1, the underlying competence in mathematical modeling had to be determined for each student both before and after the intervention based on the responses in the pre- and posttest. Following Item Response Theory, a one-dimensional dichotomous Rasch model (1-PL model) was used for this purpose. Any tasks that were not answered were treated as if they had been solved incorrectly. Afterwards, a mixed model ANOVA was conducted to investigate differences within time between the two groups.

To answer research question RQ2, for each of the tasks 1, 2, 3, 5 and 8 a two-sided Mann-Whitney U test was applied to the data obtained by the cognitive load instrument.

Results

Mathematical Modeling Competence

The Rasch model for the investigated data showed an EAP reliability of .723 for the pretest and .701 for the posttest. Thus, it can be stated that the data met the requirements for a Rasch model. The estimation of the Rasch model was run with the R package *TAM* version 3.7.16.

The mixed model ANOVA of the mathematical modeling competence development within time between the two device provisioning concepts BYOD and pool revealed no significant difference ($p = .876$). The R package used to run the ANOVA was *ez* version 4.4.0. Figure 1 presents the mean and standard deviation as well as the distribution of the students' mathematical modeling competence of the two groups BYOD and pool at both time points. This part of the study has already been presented in Krause (in press).

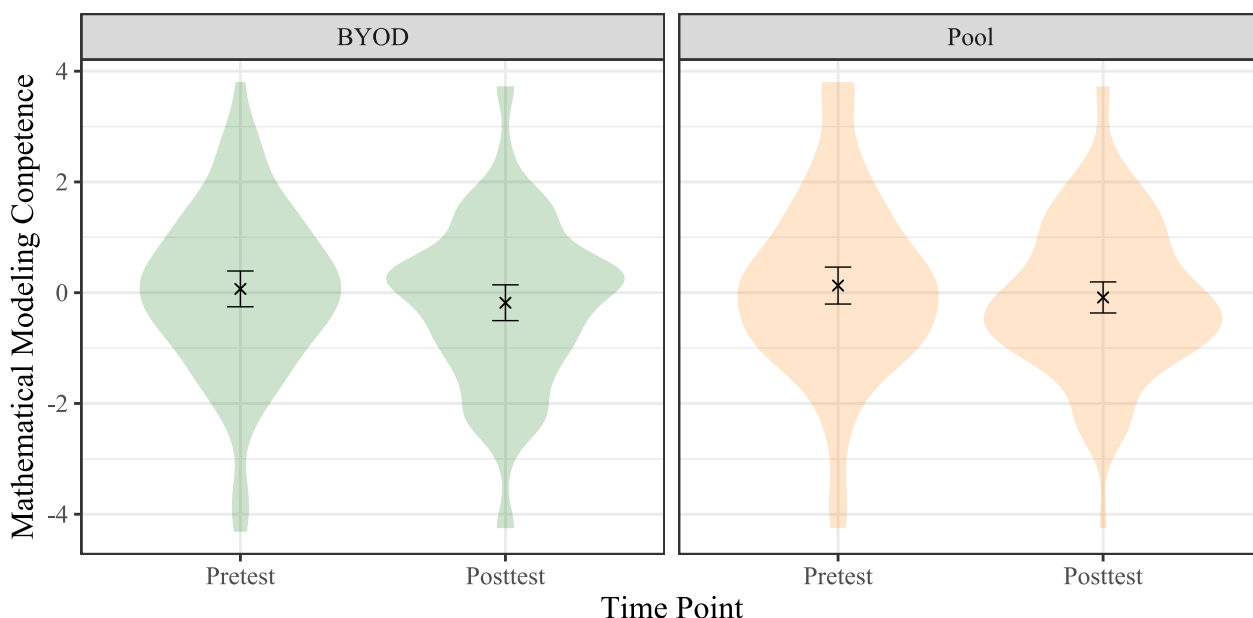


Figure 1: Mean With 95% Confidence Interval and Distribution of Students' Mathematical Modeling Competence

Cognitive Load

For task 8, students who used their own device to complete the task ($Mdn_{BYOD} = 7$, $M_{BYOD} = 6.64$) rated this task to be easier than students using a provided device ($Mdn_{Pool} = 7$, $M_{Pool} = 7.23$). A Mann-Whitney test indicated that this difference was statistically significant with small effect size, $W(N_{BYOD} = 83, N_{Pool} = 66) = 2228.5$, $z = -1.98$, $p = .047$, $r = .16$.

No significant differences were found between the two provisioning concepts for the remaining tasks 1, 2, 3 and 5 ($p = .423$; $p = .08$; $p = .579$; $p = .117$). The R package used to run the Mann-Whitney U

test was *stats* version 3.6.2. Figure 2 presents the cognitive load distribution of the two study groups as box plots with whiskers with maximum 1.5 IQR for all five tasks.

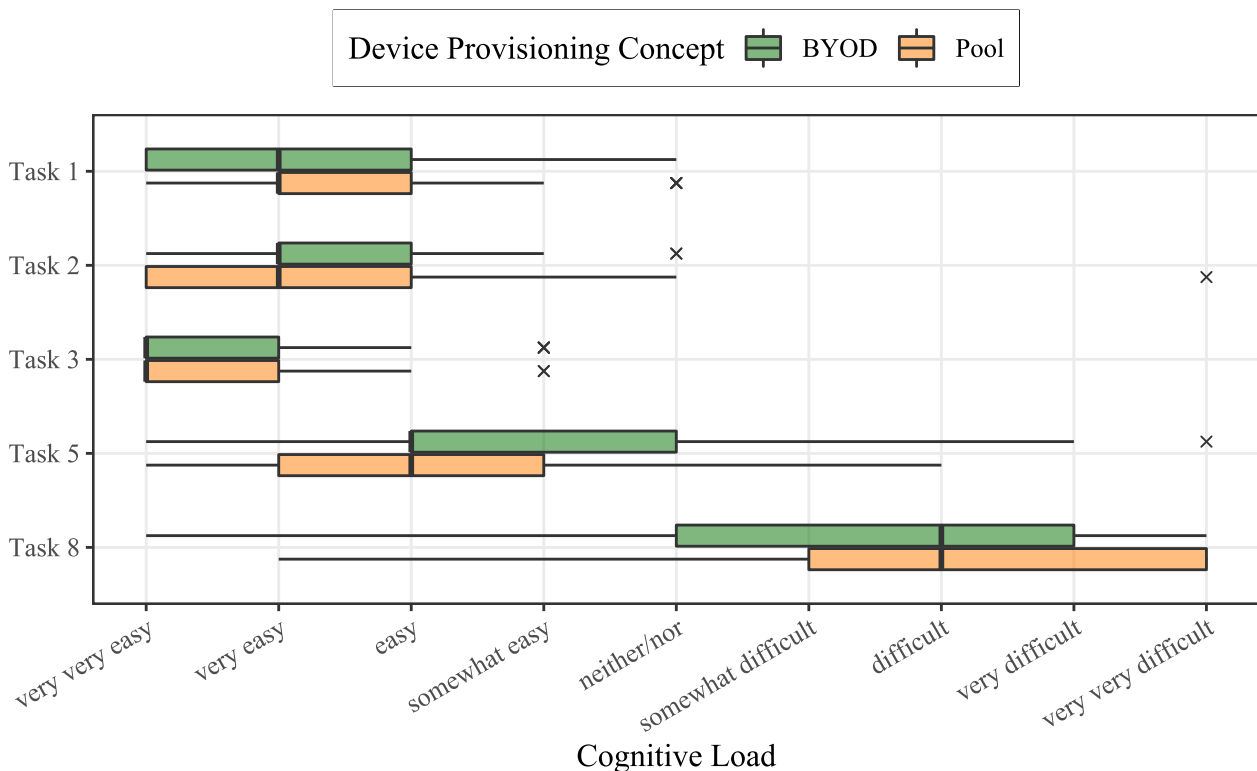


Figure 2: Cognitive Load of the Students Regarding Different Tasks

Discussion

As can be seen in Figure 1, there are only slight and non-significant differences in the students' mathematical modeling competence development within time and between the groups for this sample using the current analysis. To further investigate the research question, it is planned to repeat the analysis with a larger sample and also to consider other IRT models.

As can be seen in Figure 2, task 8 is rated as more difficult by the learners than the other tasks (in terms of 0.25-, 0.5- and 0.75-quantiles). In both experimental groups, only 25 percent of the students rated the cognitive load of task 8 as *neither/nor* or easier; whereas for all four other tasks, 75 percent of the students rated these tasks as *neither/nor* or easier. This raises the question of the extent to which the difference in cognitive load between the two groups depends on the task's cognitive load itself, possibly in particular on the cognitive load caused by the performed digital activities. Further, it is noticeable that exactly the last surveyed task shows a significant difference in cognitive load. This raises the question of the extent to which the duration of digital device use influences the observed effect. It is possible that the benefits of the BYOD concept will take effect after a (short) period of getting used to using one's own digital device at school.

Overall, we take the reported effects as indications that the advantages of using student-owned devices in the classroom may offset or exceed the disadvantages. Nevertheless, further analysis is needed to corroborate this interpretation. So far, it remains open what impact the single characteristics

of the two device provisioning concepts (cf. Table 1) have on the results and thus also to what extent the results can be applied to other provisioning concepts (e.g., GYOD or COPE).

Acknowledgment

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