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The Effect of Direct Instruction and Interactive Instructional Videos on Learning Effectiveness and Efficiency in Mathematics Education

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Abstract

This study focuses on the empirical examination of learning effectiveness and efficiency concerning two instructional methods: Direct instruction and interactive instructional videos. An SPF-2×2•2 design is used to control the instructional method, lessons, and class context. Learning outcome on probability calculation is assessed about effectiveness (grade) and efficiency (time required). The empirical findings show that learning with interactive instructional videos performs well regarding direct instruction. This is a significant result in the digitization of instructional methods.

Keywords: instructional methods, direct instruction, interactive instructional videos, experimental study, learning effectiveness and efficiency.

A. Introduction

Answering the questions of which instructional methods are suitable for the school, which instructional methods to use in the individual subjects, and how instructional methods support the learning process present challenges for general education and education in individual subjects.

Direct instruction is a teacher-oriented instructional method in which the instructor assumes the central role in directing the teaching until the end of the learning process (Petty, 2009). Interactive instructional videos can be seen as a digital variant of the presentation's instructional method (Petty, 2009). Learning videos are used to initiate and control learning and thinking processes to develop learning content independently.

Direct instruction and interactive instructional videos can be positioned using the reference frame by Wiechmann and Wildhirt (2015) (see Figure 1). In instruction control, the difference is that the interactive instructional videos are more student-controlled than direct instruction. With interactive instructional videos, students have various ways to handle the lesson because they have more alternatives. They have occasions to find out more about the subject and to contribute to the lesson. With direct instruction, the students hardly have alternatives since the teacher strongly directs teaching. Regarding the dimension of mediation style, there is a difference between the two methods as well. Students can discover "something new" with the interactive instructional videos, although guided by predefined interactive videos, with direct instruction, the subject is expositorily mediated.

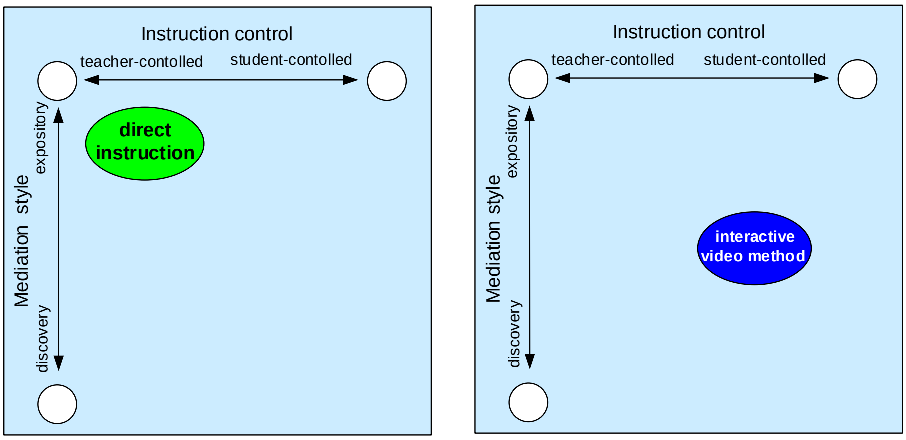

Figure 1. The Positioning of direct instruction and interactive instructional videos

The study by Zendler, et al. (2019) on the assessment of instructional methods by mathematics teachers gives first answers to which instructional methods are suitable for which knowledge processes. In mathematics teachers' opinion, direct instruction and presentation are suited to the knowledge processes of build, process, and apply – but differently well (see Figure 2).

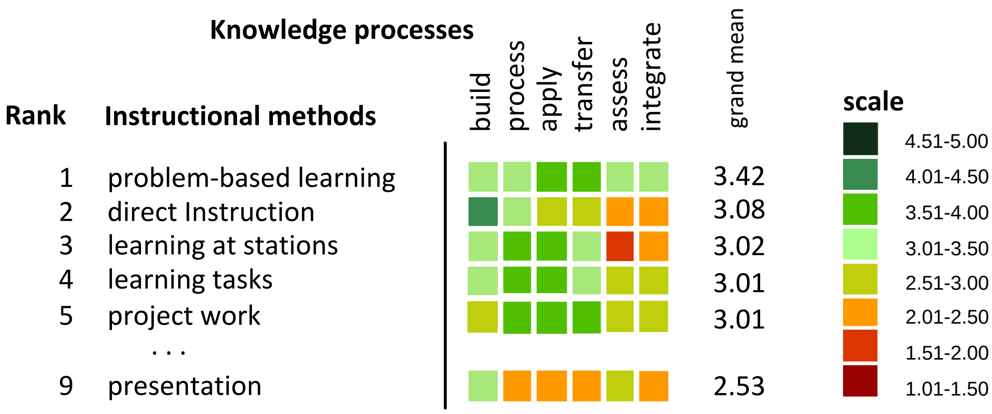

Figure 2. Means of selected instructional methods visualized for knowledge processes (adapted from Zendler, et al., 2019)

The findings in the study by Zendler, et al. (2019) were *subjective* assessments by mathematics teachers on instructional methods' learning effectiveness. So far, it has not been sufficiently clarified whether these assessments are also reflected in authentic mathematics lessons. With these findings and assessments, however, it is not possible to clarify which of two instructional methods are actually effective and efficient in the practical use of lessons, especially in mathematics education.

In digitizing instructional methods, interactive instructional videos will play a major role in the future classroom. Therefore, it makes sense to compare a classical instructional method (direct instruction) with an instructional method that relies heavily on digitization.

In digitization instructional methods, it is important to see whether interactive instructional videos as a digital variant of the instructional method of presentation can achieve similarly good learning outcomes as with the classical method of direct instruction. Thus, the present study concentrates on the empirical comparison of the effectiveness and efficiency of the two methods of interactive instructional videos and direct instruction.

Considering the fact that there is little empirical material to date on instructional methods in mathematics education, three objectives are central to the study:

(1) Direct instruction vs. interactive instructional videos: Which instructional method performs better with respect to learning on *probability calculations*? The answer to the first question is the main interest of this study. However, it must be seen in the context of answering two further questions.
(2) Class context: Are there any class differences for learning outcome on *probability calculations* when direct instruction or interactive instructional videos are used? The control of the class context is important because it can verify whether instructional methods in different classes have similar effects. If they do not have similar effects, class effects for different learning outcomes must also be considered.
(3) Learning outcome: Learning outcome is a complex construct that can only be grasped through the interplay of several variables. Thus, the question arises as to whether the learning outcome differs by using direct instruction and computer simulation, particularly for learning effectiveness and learning efficiency?

The following research hypothesis is linked to these three objectives:
"In mathematics education (grade 9, secondary school), direct instruction performs better than interactive instructional videos with respect to learning outcome (effectiveness and efficiency) on *probability calculations.*"

B. Literature Review

The wide range of instructional methods is almost incomprehensible. The *Center for Teaching and Learning* (2018) cites 150 instructional methods, Gugel (2011) more than 2,000 methods, including their variations. Handbooks describing instructional methods are provided by authors such as Ginnis (2001), Abell and Lederman (2007), Davis (2009), Petty (2009). A useful definition of the method comes from Huber and Hader-Popp: "The word method is understood to mean a clearly defined, conceptually perceivable and independent, if also integrated, component of teaching." (Huber, & Hader-Popp, 2007, p. 3)

For mathematics education, a number of good standard reference work is available which addresses the application of instructional methods (Zech, 1998; Heddens, Speer, & Brahier, 2008; Kidwell, & Ackerberg-Hastings, 2008; Barzel, et al., 2011; Reiss & Hammer; 2014; Cruickshank, et al., 2011; Li, et al., 2014; Ufer, et al., 2015; Djidu & Jailani, 2017; Jailani et al., 2018).

Hattie (2009, chapters 9 and 10) provides information on the effectiveness of instructional methods. High effect sizes (d > .50) were demonstrated for microteaching (d = .88), reciprocal teaching (d = .74), feedback (d = .73), problem solving (d = .61), direct instruction (d = .59), mastery learning (d = .58), case study (d = .57), concept mapping (d = .57), peer tutoring (d = .55), cooperative (vs. competitive) learning (d = .54), and interactive instructional videos (d = .52).

Honebein and Honebein (2015) studied 31 instructional methods regarding effectiveness, efficiency, and appeal from instructional designers' perspectives. They studied the influence of learning domains (cognitive, psychomotor, affective, and interpersonal) and learning outcomes (effectiveness, efficiency, and appeal) on designer judgments of useful instructional methods. Their results show that learning domain, learning outcome, and the interaction of domain and outcome are relevant to the usefulness of methods.

Hiebert and Grouws (2007) state that there is still no elaborate theory in mathematics education on teaching methods that makes statements about (1) the effectiveness of different teaching methods for different learning goals, (2) the system of interacting features, and (3) the influence of mediating variables. The absence of a theory in mathematics education on teaching methods is not surprising because, so far, empirical studies that comparatively assess the learning effectiveness of instructional methods for mathematics education are rare.

Teaching examples for mathematics education, employing direct instruction, are not as numerous as might be assumed. Amberg (2014) shows that direct instruction is well suited for basic mathematical skills such as process-related competencies. Ewing (2011) provides a detailed report on the advantages and disadvantages of direct instruction in mathematics education.

Videos with mathematical content are numerous (for example, Helmke, 2019; Schärer, 2019; Schumann, 2019). Lessons, which use learning videos in mathematics education, are few. A field study on using problem-based learning videos in open mathematics lessons (Fößl, 2019) showed a significantly higher learning outcome with the problem-based learning setting.

C. Methodology

1. Study Design

Experimental design. An SPF-2×2•2 experimental design (Split Plot Factorial design, 3-factor design with repeated measures for factor *B,* see Figure 3) is used to test the research hypothesis (Kirk, 2013).

	b_1	b_2
a_1c_1	s_1 … s_n	s_1 … s_n
a_1c_2	s_{n+1} … s_{2n}	s_{n+1} … s_{2n}
a_2c_1	s_{2n+1} … s_{3n}	s_{2n+1} … s_{3n}
a_2c_2	s_{3n+1} … s_{4n}	s_{3n+1} … s_{4n}

A = Instructional methods
a_1 = direct instruction
a_2 = interactive video method

B = Lessons
b_1 = lesson #1
b_2 = lesson #2

C = Class
c_1 = 9b
c_2 = 9d

Figure 3. The layout of the SPF-2×2•2 design

Independent variables. Factor *A* represents the instructional methods: a_1 = direct instruction, a_2 = Interactive instructional videos. Factor *B* represents two lessons: b_1 = lesson #1, b_2 = lesson #2. Factor *C* represents classes: c_1 = class 9b, c_2 = class 9d.s_1, ..., s_{4n} represent students.

Dependent variables. The dependent variables are used to assess student effectiveness and efficiency when solving tasks on probability calculations. The assessments refer to (1) grades and (2) time required to solve tasks. The assessments of tasks are carried out on a six-point grading scale from 1 ("very good") to 6 ("insufficient"). The time required is measured in minutes.

Power analysis. The sample size for the SPF-2×2•2 experimental design (Mueller & Barton, 1989; Mueller et al., 1992) is determined with a type II power analysis – *N* as a function of power (1-β), Δ and α . The desired power (1-β) is 0.80, and only large effects (Δ = 0.80) in relation to the dependent variable are classified as significant; the significance level is α = 0.05. Then a total sample of approximately N^* = 44 students (n_1^* = 22 students for a_1, n_1^* = 22 students for a_2) is needed based on the power calculations by PASS (NCSS, 2018) with respect to ε-corrected *F*-Tests (Mueller & Barton, 1989; Mueller, at al., 1992).

Operational test hypothesis. Given the study design and the above specification of the independent and dependent variables, the operational hypothesis of the study can be formulated as follows: "In mathematics education (grade 9, secondary school), direct instruction performs better than interactive instructional videos with respect to learning outcome on *probability calculations,* operationalized by (1) an achievement test on probability calculations, and (2) time required to solve tasks of the achievement test."

2. Instruments

Sample. For the study, two classes of grade 9 with a total of 51 students from the "Realschule Korntal-Münchingen" were selected. The following criteria were important for the selection of these classes: (1) mathematics s offered in both classes, (2) both classes can be instructed with the same lesson, (3) timeliness in teaching must be adhered to.

The school's half-class organization was used for the investigation: the two selected classes were divided into four equal groups. 27 students were taught by direct instruction, and interactive instructional videos instructed 25 students. In class 9b, 14 students were taught by direct instruction, and interactive instructional videos instructed 13 students. In class 9d, 13 students were taught by direct instruction, and interactive instructional videos instructed 12 students. The students had experience with the two instructional methods.

Two lessons were carried out with the two instructional methods: A 90-minute lesson (lesson #1) and a 45-minute lesson (lesson #2). The 90-minute lesson (lesson # 1) and the 45-minute lesson (lesson #2) were completed with a test.

Learning content. Learning content on the one hand and instructional methods on the other are interdependent. To compare instructional methods, it was important to have learning content, which can be taught using instructional methods. *Probability calculations* is one such topic. It contributes to content and process concepts of mathematics education and is consistent with the requirements of educational standards for mathematics education (NCTM, 2000), and thus receive their educational legitimacy.

Learning content for both classes is the same, has the same structure and conditions, except that it takes place on different days of the week. The two lessons are done on two separate days within one week. Previously, the subject of probability calculations was introduced to create a frame of reference.

3. Lessons

Lessons were conducted by a female teacher (24 years old) who has undergone intensive training on instructional methods for mathematics education. With direct instruction and interactive instructional videos, this teacher planned both lessons; this teacher-developed all materials.

3.1 Lessons with direct instruction

The lessons were carried out according to the five steps for direct instruction (see Figure 4): (1) *Introduction.* The instructor informs the students what they will learn by the end of the class (learning objective and learning content). (2) *Presentation/Demonstration*. The instructor presents/demonstrates the topic in small steps until the entire topic has been presented. (3) *Joint exercises.* The instructor conducts exercises together with the students according to the main rule of direct instruction: posing numerous, incremental questions to challenge the active use of the new knowledge. (4) *Individual exercises*. The students conduct exercises individually to automate the newly acquired knowledge, even without direct feedback from the instructor. (5) *Stocktaking.* At the end of the lesson, there is a summary of the learning outcome compared to the introduction's goals.

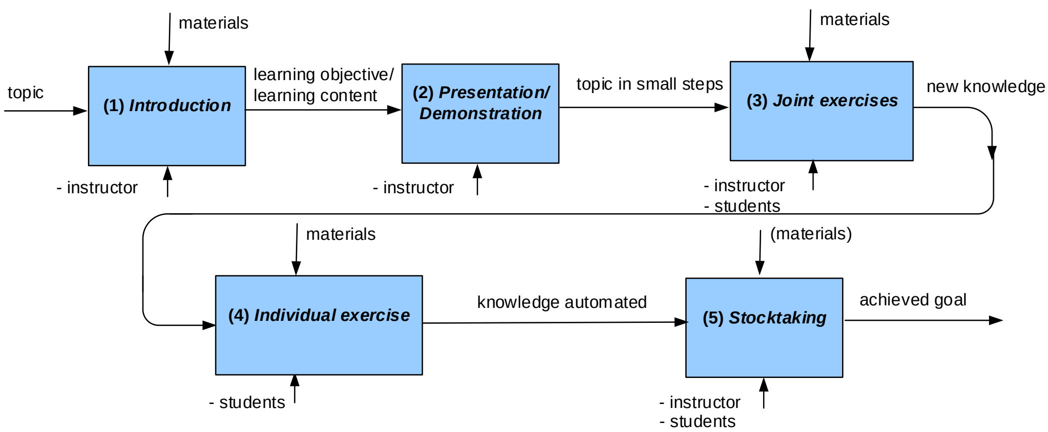

Figure 4. The Process model for direct instruction

Lesson #1 introduces the terms random experiment, Laplace probabilities, relative frequency, experiment events, formula for calculating relative frequency, and tree diagram. Figure 5 shows the complete blackboard after lesson #1. Lesson #1 was completed with a test on using a tree diagram and the rule of product.

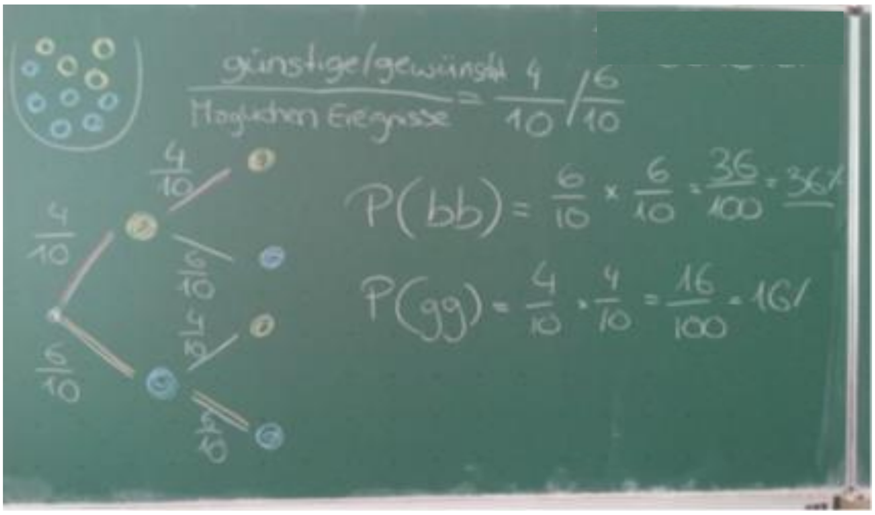

Figure 5. Blackboard after lesson #1

Content of lesson #2 is the *model without replacement*. As an example, the teacher introduces a parking garage. The question is, "What is the probability that two cars of the same color leave the garage one after the other?" The task involves four red and two green parked cars. For a better understanding, a sketch is used, as Figure 6 shows. Lesson #2 was completed with a test on drawing without replacement and the rule of sum.

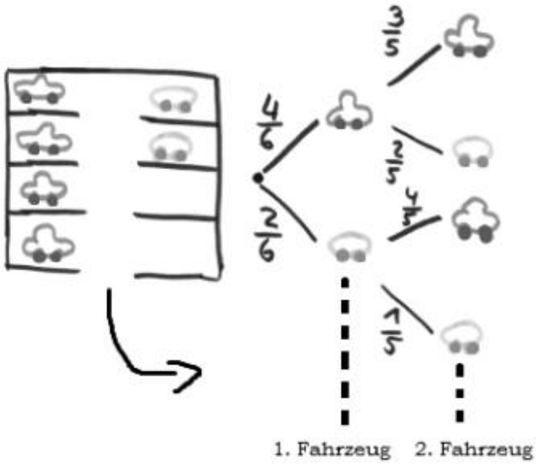

Figure 6. Parking garage task by using a tree diagram after lesson #2

3.2 Lesson with interactive instructional videos

The lessons were carried out according to the four steps for interactive instructional videos (see Figure 7): (1) *Selection of instructional videos*. The instructor selects instructional videos available on YouTube (Keddie, 2017) related to the subject matter, taking into account quality criteria, particularly for self-directed learning. (2) *Provision of instructional videos*. The teacher provides instructional videos to the students in the classroom. (3) *Explanation of the subject matter*. The teacher only explains the subject to the extent that the students can then deepen it with learning videos and work independently. (4) *Content processing*. The students work independently on the content of the learning videos, plan, and carry out the tasks, control themselves.

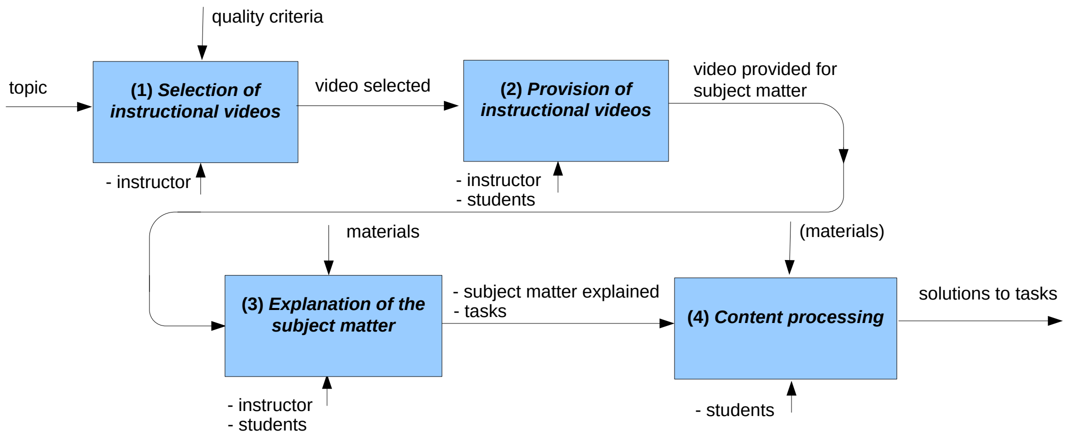

Figure 7. The Process model for interactive instructional videos

While with direct instruction, lesson #1 is mostly executed by the teacher, interactive instructional videos use the Moodle platform to perform instructions. To do this, students log in to Moodle at the beginning of the lesson. A first worksheet contains the basic concepts of probability calculations accompanied by three videos (see Figure 8 for an example). Lesson #1 was completed with the same test as used in lesson #1 with direct instruction.

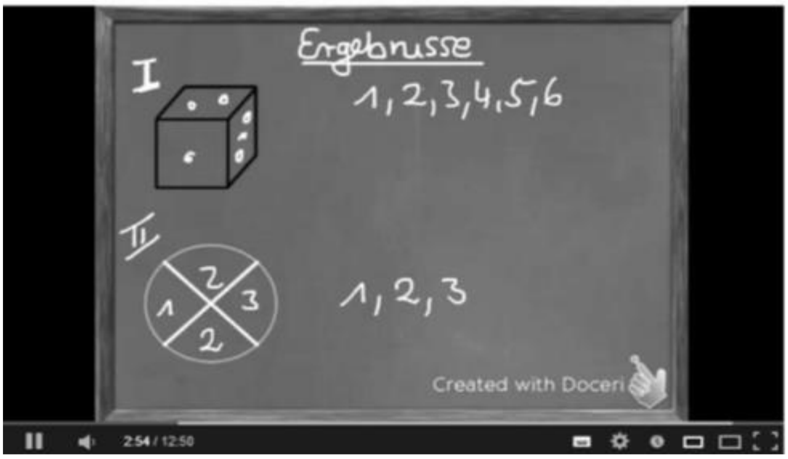

Figure 8. One of three videos used in lesson #1(see Kück, 2019)

Lessons #2, with interactive instructional videos, had more time pressure than lesson #2 with direct instruction. The students need to learn the same content with greater *technical* effort because booting, logging in are related to a loss of time. The rule of the sum is explained using the tree diagram (see Figure 9). Lesson #2 was completed with the same test as used in lesson #2 with direct instruction.

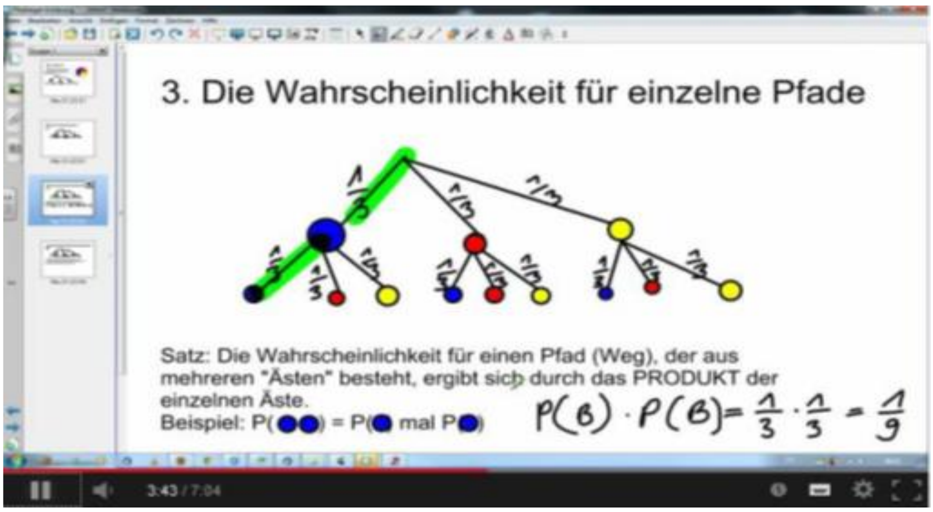

Figure 9. Explanations of path rule (see Weh, 2018) after lesson #2

4. Procedure for Data Analyses

Appendix contains the data set obtained for the SPF-2×2•2 design with *n*11 = 14 students and *n*12 = 13 of class 9b, *n*21 = 13 and *n*22 = 12 students of class 9d.

In analyzing our empirical data (see Appendix 1), the following procedure is carried out: (1) First, we analyze the data descriptively. (2) Then, we conduct a three-way analysis of variance with repeated measures by the SPF-2×2•2 split-plot design).

Data analyses were conducted using SPSS 24.0 and R (package n part LD); power analysis was computed with PASS 15 (NCSS, 2018).

D. Findings and Discussions

1. Findings

1.1 Descriptive Findings

1.1.1 Learning effectiveness (grade)

The results of learning effectiveness, including the class context, are illustrated in Figure 10. They show means and 95% confidence intervals for learning outcomes. The results are mixed. While in class 9b with direct instruction, learning effectiveness was slightly better after the second lesson than video-based lessons, which was not the case in class 9d. Class 9b tended to have better learning outcomes than class 9d. For both instructional methods, learning effectiveness is relatively homogeneous (see the 95% confidence intervals).

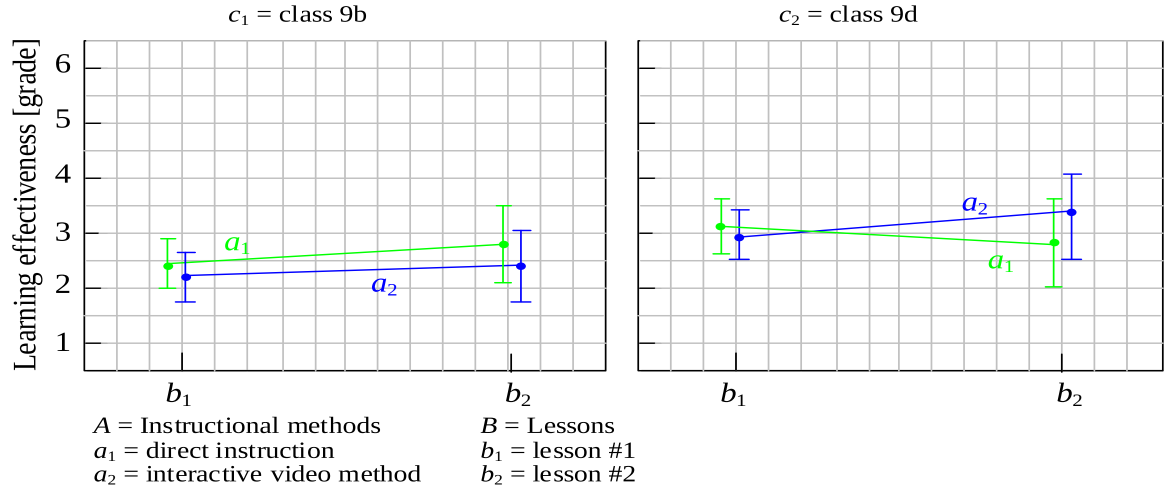

Figure 10. Means and 95% confidence intervals for learning effectiveness [grade]

1.1.2 Learning efficiency (time required)

The findings on learning efficiency are shown in Figure 11. The findings are more consistent than the findings on learning effectiveness: With the video-based lessons and direct instruction, tasks are handled faster after lesson #2 than in lesson #2, in both classes. For both instructional methods, the time required to solve the tasks are relatively heterogeneous, as the 95% confidence intervals show.

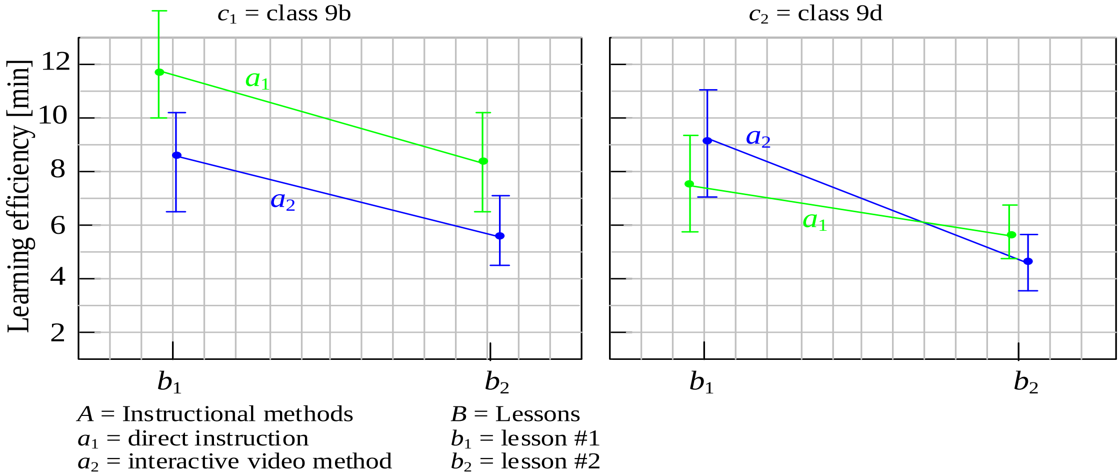

Figure11. Means and 95% confidence intervals for time required

1.2 Analysis of Variance

To assess whether direct instruction differs from interactive instructional videos on learning effectiveness(grade) and efficiency (time required), the seven null hypotheses according to an SPF-2×2•2 design were tested at the significance level of $\alpha = 0.05$

Testing the statistical assumptions. For an analysis of variance (ANOVA), the data of an SPF-2×2•2 design must be normally distributed and variance homogeneous. The normal distribution was tested with the Shapiro-Wilk test and variance homogeneity with the Levene test. Both assumptions were not met ($p<.05$).

The data are, therefore, the first rank transformed and then analyzed by using the Q*N* test described by Brunner, Domhoff, and Langer (2002, chapter 5). The Q*N* test can be used to test the effects (including combinations) of factors and *B;* in addition, the effects of a repeated-measures factor *C* can be analyzed. The software package *nparLD* of R (Noguchi, et al. 2012) is used to calculate the test statistics. Tables 3.1 and 3.2 contain the results analyzed by the Q_N test.

1.2.1 Leaning effectiveness (grade)

Table 1 summarizes the results of the Q_N test for learning effectiveness.

Table 1. Q_N test (Wald type) for learning effectiveness (grade)

Source of variation	Q_N	*df*	*p*
between			
A (instructional method)	0.32	1	< .58
C (class)	12.77	1	< .01
A × C	1.38	1	< .24
within			
B (lessons)	0.32	1	< .58
A • B	3.34	1	< .07
C • B	0.67	1	< .41
A × C • B	0.83	1	< .36

The main effect *A* (direct instruction vs. interactive instructional videos) was not significant at the α level of 0.05 ($Q_N(A) = 0.32$, $p < 58$): The corresponding H_0 was retained: Learning effectiveness with direct instruction is higher than with interactive instructional videos.

The main effect *B* (lesson #1 vs.lesson #2) was not significant at the α level of 0.05 ($Q_N(B) = 0.32$, $p < .58$). The corresponding H_0 was not rejected in favor of $H1$: Learning effectiveness after lesson #1 is not higher than after lesson #2.

The main effect *C* (class 9b vs. class 9d) was significant at the α level of 0.05 ($Q_N(C) = 12.77$, $p < .01$). The corresponding H_0 was rejected: Class 9b and class 9d differ concerning learning effectiveness.

The interaction effect *A* • *B* (instructional methods • lessons) was not significant at the α level of 0.05 ($Q_N(A \cdot B) = 3.34$, $p < .07$). The corresponding H_0 was not rejected: Direct instruction and interactive instructional videos are not different in terms of learning effectiveness in relation to lessons.

The interaction effect *A* × *C* (instructional methods × class) was not significant at the α level of 0.05 ($Q_N(A \times \mathrm{C}) = 1.38$, $p < .24$). The corresponding H_0 was not rejected: Direct instruction and interactive instructional videos are not different in terms of learning effectiveness for the two classes.

The interaction effect *C* • *B* (class • lessons) was not significant at the α level of 0.05 ($Q_N(C \cdot B) = 0.67$, $p < .41$). The corresponding H_0 was not rejected: The two classes are not different in learning effectiveness with lessons.

The interaction effect *A* × *C* • *B* (instructional method × class • lessons) was not significant at the α level of 0.05 ($Q_N(A \times C \bullet B) = .83$, $p < .36$). The corresponding H_0 was not rejected: Direct instruction and interactive instructional videos do not differ concerning learning effectiveness with the two classes and lessons.

1.2.2 Efficiency (time required)

Table 2 summarizes the results of the Q_N test for learning efficiency.

Table 2. Q_N test (Wald type) for learning efficiency (time required)

Source of variation	Q_N	*df*	*p*
between			
A (instructional method)	3.05	1	< .01
C (class)	4.82	1	< .01
A × C	4.20	1	< .01
within			
B (lessons)	73.68	1	< .01
A • B	1.58	1	< .21
C • B	0.07	1	< .79
A × C • B	2.23	1	< .14

The main effect A (direct instruction vs. interactive instructional videos) was significant at the α level of 0.05 ($Q_N(A) = 3.05$, $p < .01$). The corresponding H_0 was rejected: Learning with interactive instructional videos more efficient than with direct instruction.

The main effect B (lesson #1 vs. lesson #2) was significant at the α level of 0.05 ($Q_N(B) = 73.68$, $p < .01$). The corresponding H_0 was rejected: Learning after lesson #2 is more efficient than after lesson #1.

The main effect C (class 9b vs. class 9d) was significant at the α level of 0.05 ($Q_N(C) = 4.82$, $p < .01$). The corresponding H_0 was rejected: Class 9b and class 9d differ concerning learning efficiency.

The interaction effect $A \bullet B$ (instructional methods • lessons) was not significant at the α level of 0.05 ($Q_N(A \cdot B) = 1.58$, $p < .21$). The corresponding H_0 was retained: Direct instruction and interactive instructional videos are not different in terms of learning efficiency with lessons.

The interaction effect $A \times C$ (instructional methods × class) was significant at the α level of 0.05 ($Q_N(A \times \mathrm{C}) = 4.20$, $p < .01$). Therefore, the corresponding $H0$ was rejected: Direct instruction and interactive instructional videos are different in terms of learning efficiency for the two classes.

The interaction effect $C \bullet B$ (class • lessons) was not significant at the α level of 0.05 ($Q_N(C \cdot B) = 0.07$, $p < .79$). The corresponding H_0 was not rejected: The two classes are different in learning efficiency with lessons.

The interaction effect $A \times C \bullet B$ (instructional method × class • lessons) was not significant at the α level of 0.05 ($Q_N(A \times C \bullet B) = 2.23$, $p < .14$). The corresponding H_0 was not rejected: Direct instruction and interactive instructional videos do not differ concerning learning efficiency with the two classes and lessons.

E. Conclusions

The present study's main result is that the research hypothesis – in mathematics education (grade 9, secondary school), direct instruction performs better than interactive instructional videos for learning outcome on *probability calculations* – can be maintained.

Performance of instructional methods. With regard to question 1, direct instruction and interactive instructional videos are effective for learning probability calculation. Having shown the learning effectiveness of interactive instructional videos is an important result of this study.

Class context. Regarding question 2, the following can be said: The students' learning effectiveness in both classes was not equal. The interaction diagram for class 9d shows a disordinal method × class interaction effect, which was even statistically significant. However, the statistical effect does not seem to be meaningful in learning effectiveness. In any case, in both classes, direct instruction performs better than interactive instructional videos, in-class 9d even better than in class 9b.

Learning effectiveness *and efficiency.* About question 3, direct instruction and interactive instructional videos are effective on *probability calculations*. Concerning efficiency, interactive instructional videos performed better than direct instruction.

Comparing the findings with those of others. The findings are compatible with the findings on direct instruction (Fischer & Tarver, 1997; Hattie, 2009) and interactive instructional videos (Küng, 2019). They are important to supplement the knowledge about the learning effectiveness of instructional methods in mathematics education, especially when it comes to digital transformations of instructional methods. Moreover, the results of this study reflect the findings in the study of Zendler, et al. (2019), especially they show that subjective assessments of mathematics teachers are not sufficient to evaluate the learning effectiveness of instructional methods. Only studies that (experimentally) investigate instructional methods in authentic mathematics lessons can provide sufficient insights.

Recommendations for mathematics education. The following recommendations can be made for practical use of the two studied instructional methods: Both methods can be used in mathematics education, especially when it comes to new teaching material in digital settings. With new teaching material, direct instruction has advantages over interactive instructional videos because the teacher can convey knowledge directly to the students. For current mathematics education topics, interactive instructional videos are suitable because Internet information is (usually) up-to-date; students do not have to work with outdated data, as they are in schoolbooks. The interactive instructional videos can be an additional motivation for students to deal with current topics.

Limitations. The study results have only limited external validity due to the low number of participating students in only two classes and one school. In order to make more valid statements, the study should be carried out in more than two classes and more than one school by using multilevel models (Bryk & Raudenbush, 1992; Goldstein, 2010). In such models, further instructional methods should be included, whose evaluation will provide important insights for teaching mathematics.

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