Direct Instruction vs. Computer Simulation and their Learning Outcome in Engineering Education

Andreas Zendler, Manuel Gohl

Department of Computer Science, University of Education Ludwigsburg, Ludwigsburg 76431, Germany
e-mail: zendler@ph-ludwigsburg.de

Abstract- *Answers to the questions of which instructional methods are suitable for school, what instructional methods should be applied in teaching individual subjects and how instructional methods support the act of learning represent challenges to general education and education in individual subjects. This study focuses on the empirical examination of learning outcome in engineering educationwith respect to two instructional methods: direct instruction and computer simulation.An CRF 2x2 design is used to control instructional method and class context. Learning outcome on bridge constructionis assessed with reference to the optics of bridge and the material usage for the bridge. The empirical findings show that learning with direct instruction was superior to computer simulation.*

Keywords – *Education, Instructional methods, Direct instruction, Computer simulation, Experimental study.*

1. Introduction

Answers to the questions of which instructional methods are appropriate for school, what instructional methods should be applied in teaching individual subjects and how instructional methods support the act of learning represent challenges to general education and education in individual subjects. Direct instruction and computer simulation are two instructional methods for which a number of empirical findings are available. For direct instruction, Hattie [1] cites 4 meta-analyses and 304 individual studies, for computer simulation 8 meta-analyses and 361 individual studies, respectively. According to Hattie the mean effect size for direct instruction is $d = .59$; for computer simulation the effect size is $d = .33$. For computer simulation, the empirical findings are not uniform. VanSickle[2] reports that computer simulation has little advantage over traditional instructional methods. Learning effects for the development of attitudes have been shown on the one hand [2], on the other hand not [3]. For natural science subjects, LeJeune [3] showed that learning effects affect "deeper thinking", e.g. the ability to learn scientific facts or to understand scientific processes.

In recent research by Zendler, Seitz, Klaudt [4], STEM teachers evaluated 20 instructional methods in terms of six knowledge processes: build, process, apply, transfer, assess, and integrate (see Figure 1). The heat map also contains the grand means of the knowledge processes for some instructional methods. The instructional methods are sorted in accordance with these grand means.
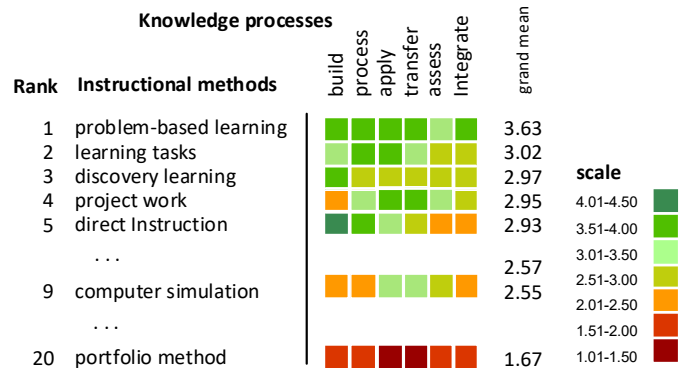

Figure 1. Means of the instructional methods visualized for knowledge processes.

Figure 1 shows that problem-based learning was assessed by STEM teachers as the best method for supporting the act of learning; this method is followed by four additional instructional methods: learning tasks, discovery learning, project work, direct instruction. In a more detailed observation the heat map reveals that

problem-based learning is distinguished by high values (> 3.00) for all knowledge processes. Learning tasks is characterized by high values for the knowledge processes of *build*, *process, apply,* and *transfer*. Discovery learning demonstrates high values for the knowledge process *build.* Particularly high values (> 4.00) for the knowledge process *build* are shown by direct instruction (rank 5), which additionally has relatively high values (> 3.00) for the knowledge processes of *process* and *apply*, whereas computer simulation (rank 9) was highly assessed for *apply* and *transfer.* The search through current magazines on engineering education (e.g. Journal of Engineering Education, European Journal of Engineering Education, Global Journal of Engineering Education) provided findings related to instructional methods in regard to interactive teaching for increasing the effectiveness of lectures [5, to favoring inductive teaching (problem-based learning, project-based learning, case-based teaching, discovery teaching) [6], to study the influence of the inquiry learning model [7], to using concept maps as assessment techniques for knowledge integration [8] and for problem solving [9], to creating a measurement for instructional practices [10], and to applying the models method in teaching to architects [7].

1.1 Direct Instruction

Thebasic structure of this instructional method (see Figure 2) is as follows: (1) *Introduction.* Theteacher informs the students what they will learn by the end of the class (learning objective and learning content). (2) *Presentation/Demonstration*.The teacher presents/demonstrates the topic in small steps until the entire topic has been presented. (3) *Joint exercises.* Theteacher conductsexercisestogether with the students. against the backdrop of the core rule of direct instruction: posing numerous, incremental questions in order to challenge the active use of the new knowledge. (4) *Individual exercise*. The students conduct exercises individually in order to automate the newly acquired knowledge, even without direct feedback from the teacher (5) *Stocktaking.* At the end of the instruction stock is briefly taken of what has been learned in relation to the introduction.

Lesson examples of direct instruction with technical content are relatively rare because other instructional methods are favored in engineering education(e.g., project, experiment, case study). However, examples can be found in textbooks for direct instruction [12-15]. Bruckmann[16] publishes an extensive collection of worksheets that can be used, e.g. worksheets for measuring, drawing, soldering, scribing, switching, controlling and regulating.

1.2Computer simulation

Thisinstructional method (see Figure 3) comprises six steps: (1) *Introduction*. The students receive a problem-based introduction from the teacher on an educational subject. (2) *Problem definition.* With the support of the

teacher, the students propose hypotheses on solving the problem in relation to the subject. (3) *Planning*. The students establish what interventions they want to undertake in the simulation software in order to solve the problem (or to understand it better). (4) *Execution and logging*.The students execute their planned interventions in the simulation software and document the information they receive as a result. (5) *Expanding the knowledge base*. The students expand and document their own knowledge base in the context of the information they have acquired from the simulation software. (6) *New hypotheses.* Thestudents propose new hypotheses and repeat the steps 3 to 6.
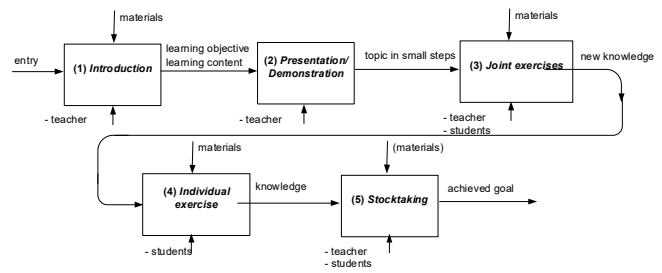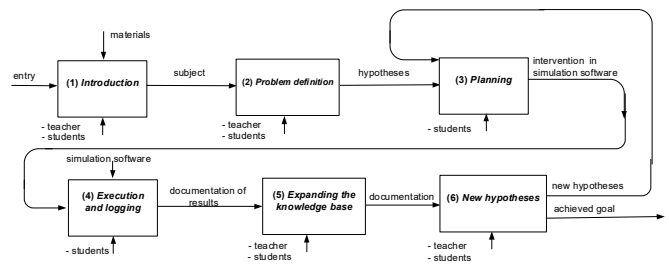

Figure 2.Process model of direct instruction.

Figure 3.Process model of computer simulation.

Lessons that use computer simulation have a long tradition in engineering education[17]). More recent teaching examples are numerous and can be found, for example, in the LOG IN journal [18-20] and text books on engineering education[12-14]. The SolidWorks Education Edition [20] allows the design and design of simple to complex parts and assemblies that can be virtually tested and optimized, e.g. on strength, aerodynamics or environmental compatibility.

1.3Positioning of the Experiment Method and Computer Simulation

By using the frame of reference by Wiechmann and Wildhirt [21], which consists of three educational dimensions (*instruction control, mediation style,* and *lesson design)*, we positioned direct instruction and computer simulation (see Figure 4). With regard to lesson design the two methods are similarly classified: They are planned lessons. Both instructional methods are different in terms of instruction control and mediation style. Concerning

92

instruction control direct instruction is very much teacher-controlled, while computer simulations is more or less student-controlled. With respect to mediation style direct instruction is expository, whereas computer simulation is discovery.
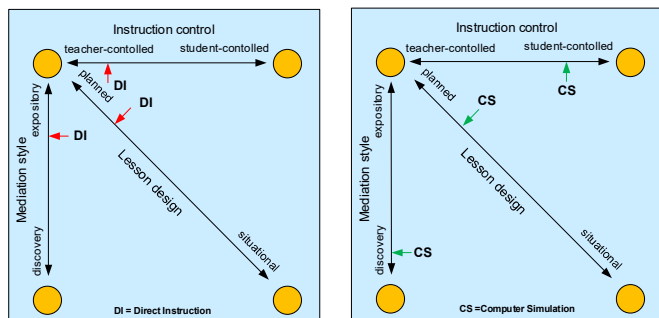

Figure 4. Positioning of direct instruction and computer simulation.

1.4 Learning Content and Instructional Methods

Learning objectives and 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 with both instructional methods. *Bridge construction* is one such topic.

For computer simulation, Bridge Constructor by Headup Games [22] was used. It contributes to content and process concepts of engineering education. Moreover, it is consistent with the requirements of educational standards for engineering education [23, 24], and thus receive their educational legitimacy.

Figure 5. Bridge Constructor.

Bridge construction belongs to the field of statics, to which the engineering practices by the *Framework for K-12 Science Education*[24]) can beapplied:

- Defining problems
- Developing and using models
- Planning and carrying out investigations
- Analyzing and interpreting data
- Using mathematics and computational thinking
- Designing solutions
- Engaging in argument from evidence
- Obtaining, evaluating, and communicating information

1.5 Research Questions

Direct instruction and computer simulation are two instructional methods, which were classified differently in the two dimensions of instruction control and mediation style. However, they are similar in lesson. The assessment of instructional methods by STEM teachers gave first answers to the questions of which instructional methods are suitable for which knowledge processes (see Figure 1). In the opinion of the STEM teachers, direct instruction is very well suited to the knowledge processes of build and process, while computer simulation is suitable for the knowledge process of apply and transfer. Hattie [1] on the other hand, found in his meta-analyses that the Hattie found that direct instruction is almost twice as effective as computer simulation (d = .59 vs. d = .33).With these findings and assessments, however, it is not possible to clarify which of the two instructional methods are actually effective in the practical use of lessons, especially in the field of engineering education. Thus, the present study concentrates on the empirical comparison of the effectiveness of both methods, in order to answer the question of how effective the two methods could be when they are used in engineering lessons.

Due to the fact there is little empirical material to date on instructional methods in educational technology, three questions are central to this study:

(1) *Direct instruction vs. computer simulation*: Which instructional method performs better with respect to learning outcome on bridge construction? 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 when direct instruction or computer simulation are used to teaching *bridge construction*? The control of the class context is important because it can be used to verify whether instructional methods in different classes have similar effects or not. If they do not have similar effects, class effects for different learning outcomes have to be considered.

(3) *Learning outcome*: Learning outcome is a complex construct that can only be grasped through the interplay of variables. Thus, the question arises as to whether learning outcome differ by using direct instruction and computer simulation, particularly with respect to optics of the bridge and material usage for the bridge?

The following research hypothesis is linked to these three questions:"In engineering education (grade 9,

93

secondary school) direct performs better than computer simulation with respect to teaching *bridge construction.*"

In the next section, we present the methods applied, describing the study design and procedures as well as the data analysis strategy. Then, we give a detailed account of our findings. In the last two sections, we discuss those findings and, finally, we draw conclusions for future research.

2. Methods
2.1 Study Design

Experimental design. A CRF-2x2 design (Completely Randomized Factorial design, 2-factor design, see Figure 6) is used to test the research hypothesis [25]. Figure 6 shows that four groups are distinguished: G_{11} contains the half-class 9a which is taught by direct instruction; G_{12} contains the half-class 9b, which is instructed by computer simulation; G_{21} contains the half-class9a, which is taught by direct instruction; G_{22} contains the half-class 9b, which is taught with computer simulation.
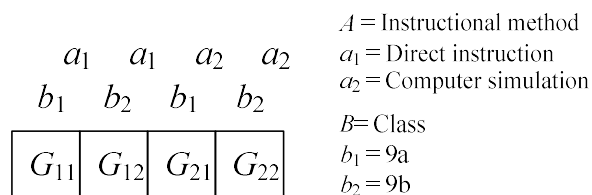
$$a_1 \quad a_1 \quad a_2 \quad a_2$$
$$b_1 \quad b_2 \quad b_1 \quad b_2$$

G_{11}	G_{12}	G_{21}	G_{22}

A = Instructional method
a_1 = Direct instruction
a_2 = Computer simulation

B = Class
b_1 = 9a
b_2 = 9b

Figure 6.   Layout of the SPF-2x2 design.

Independent variables. Factor A represents the instructional methods: a_1 = direct, a_2 = computer simulation. Factor B represents classes: c_1 = class 9a, c_2 = class 9b.

Dependent variables. The dependent variables are used to assess students´ learning outcome in bridge construction. The assessments relate to (1) the appearance of the bridge (symmetrical details and accuracy), and to (2) the material usage for the bridge (load capacity, model weight and adhesive requirements). The assessments are made on six-point grade scales (visual grade, material grade) from 1 ("very good") to 6 ("insufficient").

Power analysis. The sample size for the CRF-2x2 design is determined with a type II power analysis – N as a function of power (1-β), Δ, and α[26]. 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^* = 32 students (8 per factor combination) is needed based on the power calculations by PASS [27] with respect to ε-corrected F tests (fixed effect model).

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 engineering education(grade 9, secondary school) direct performs better than computer simulation with respect to teaching *bridge construction*operationalized by grading (1) the optics of the bridge and (2) the material usage for the bridge."

2.2 Procedure

Lessons. According to the experimental design students of two classes (b_1 = class 9a with n_1 = 15, b_2 = class 9b with n_2 = 13 pupils) are divided into two groups. While one half-class of students undergo a lesson with direct instruction (a_1), the other half-class of the students are instructed with computer simulation (a_2) using the Bridge Constructor. The lesson was conducted by a male teacher (24 years old) who has undergone intensive training in instructional methods for engineering education. Both lessons with direct instruction and computer simulation were planned by this teacher; all materials were developed by this teacher. The lesson content was the same for both classes, had the same structure and the same conditions. The instructional methods were carried out in a similar way to the illustrated execution steps (see 1.1 and 1.2).

Bridge Construction. Following the lessons, small working groups are formed, whose members come from the same groups of the lessons. Each working group is provided with the same building material: For the construction of the bridge, wooden parts must be joined with cork mats by using hot glue. The students who were instructed with direct instruction work spatially separate from the students who had been introduced by computer simulation. This prevents ideas from being copied during construction. The entire work process is documented by photographing the groups and their work steps for a subsequent evaluation. In addition, the relevant variables and their characteristics such as motivation, approach and ideas, approach and implementation, work allocation and team work, transfer from the previous hour and the use and processing of the given materials can also be analyzed at a later date.

Figure 7 shows various stages of bridge construction (working group 1) from start to finish. Stress test of the bridge. With a stress test, the bridges are tested for their load capacity.By driving over a toy car loaded with weights of different weights, the load limits of the individual bridges are shown. The stress is included in grading the bridge.

2.2 Procedurefor Data Analyses

Table 1 contains the observed data for the CRF-2×2 design with n11 = 9 and n12 = 6 students of class 9a, n21 = 7 und n22 = 6 students for class 9b. Two data sets for learning outcome (visual grade, material grade) are obtained. Table 1 contains means and standard errors of the means.
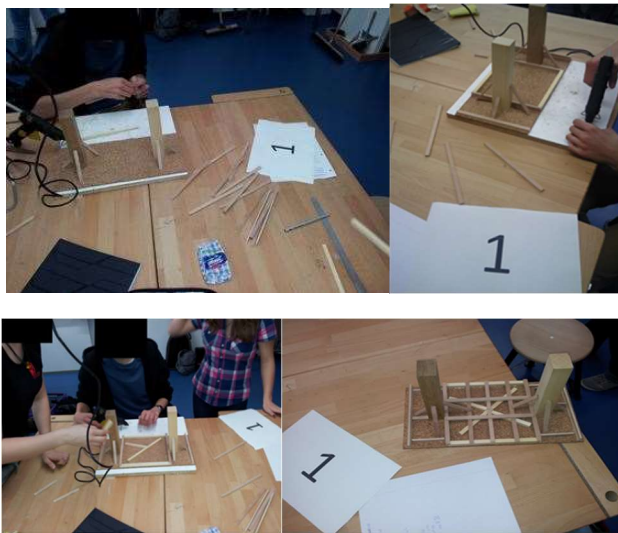
Figure 7. Various stages in bridge construction (working group 1).

Table 1. Data sets obtained for the CRF-2×2.

	a_1		a_1		a_2		a_2	
	b_1		b_2		b_1		b_2	
	Y_1	Y_2	Y_1	Y_2	Y_1	Y_2	Y_1	Y_2
	1.5	1.0	1.5	1.9	2.5	3.4	2.5	3.4
	2.0	1.0	1.5	1.0	4.0	3.6	4.0	5.2
	1.5	1.0	2.5	1.4	4.0	5.2	4.0	3.6
	2.0	1.0	1.5	1.9	4.0	3.6	2.5	3.4
	1.5	1.9	2.5	1.4	2.5	3.4	4.0	3.6
	2.5	1.4	2.0	1.0	4.0	5.2	4.0	5.2
	1.5	1.0	2.0	1.0				
	1.5	1.9						
	2.5	1.4						
$\overline{x}$	1.83	1.29	1.93	1.37	3.50	4.07	3.50	4.07
$s_{\overline{x}}$	.20	.22	.23	.24	.25	.26	.25	.26

A = Instructional method
a_1 = Direct instruction
a_2 = Computer simulation

B= Class
b_1 = 9a
b_2 = 9b

Dependent variables
Y_1 = Visual grade
Y_2 = Material grade

In analyzing our empirical data (see Appendix), the following procedure is carried out: (1) First, we analyze the data descriptively. (2) Then, we conduct two-way analyses of variance in accordance with the CRF-2x2 design.

3. Results
3.1 Descriptive Analyses
*Optics of the bridge.*The results on the optics of the bridge are illustrated in Figure 8. It shows box plots and means of the data set from Table 1 as well as 95% confidence intervals. It is noticeable that with direct instruction the learning outcome is much higher (at least 1 grade) than computer simulation - in both classes. The learning outcomes are relatively homogeneous for both instructional methods, as the 95% confidence intervals.
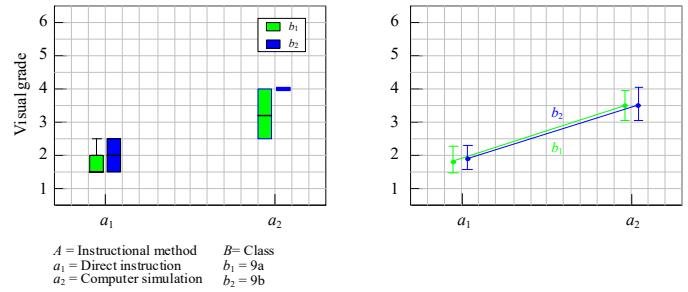

Figure 8. Results on optic of the bridge.

Material usage for the bridge. Figure 9 shows the results on material usage for the bridge. It illustrates box plots and means of the data set from Table 1 as well as 95% confidence intervals. Again, direct instruction compared to computer simulation performs better (at least 2 grades) - in both classes. The learning outcome for material usage are about as homogeneous as for the optics of the bridge; this is shown by the 95% confidence intervals.
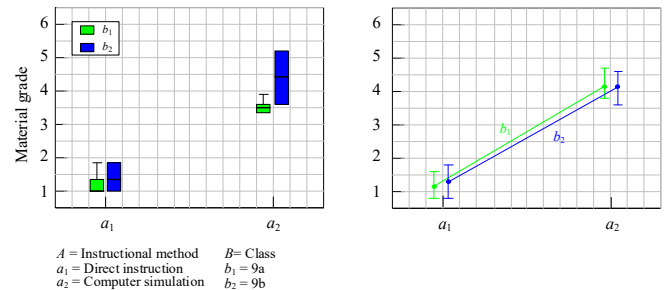

Figure 9. Results on material usage for the bridge.

3.1 Statistical Analyses
To examine whether direct instruction differs from computer simulation with respect to learning, we formulated three statistical hypotheses, which were tested at the significance level of α = 0.05.
Statistical hypotheses. The three null hypotheses were as follows:

i) the means (visual grade, material grade) of the instructional method μ_1 under factor level a_1 (direct instruction) are equal or less compared to the means of the instructional methods μ_2 under the factor levela_2 (computer simulation), such that:

$$H_0^A: \mu_1 \le \mu_2 (H_1^A: \mu_1 > \mu_2);$$

ii) the means (visual grade, material grade) of the instructional method μ_1 under factor level c_1 (class 9a) and μ_2 under c_2 (class 9b) are equal, such that:

$$H_0^B: \mu_1 = \mu_2;$$

iii) the means (visual grade, material grade) of the instructional methods $\mu_{1\bullet1}, \mu_{1\bullet2}, \mu_{2\bullet1}, \mu_{2\bullet2}$ under the

95

2 • 2 levels of factor combinations $A \times B$ are equal, such that:

$$H_0^{A \times B}: \mu_{11} = \mu_{12} = \mu_{21} = \mu_{22.}$$

Testing the statistical assumptions. For an analysis of variance (ANOVA), the data of a SPF-2x2 design must be distributed normally and variances must be homogeneous. The normal distribution was tested with the Shapiro-Wilk test and variance homogeneity with the Levene test. Both tests were significant ($p > .05$).

Thus, the data cannot analyzed by using a conventional (parametric) ANOVA.The data are therefore first rank transformed and then analyzed by using ANOVAs for rank data, that is the $F_N$test described by Brunner and Munzel (2013, p. 137–139).

Tables 2 and 3 contain results of the $F_N$test (optics of the bridge, material usage for the bridge) whose test statistic $F_N(T_A)$ is asymptotically χ^2-distributed, with $df = p–1$. $F_N(T_B)$ is asymptotically χ^2--distributed with $df = q–1$, and $F_N(T_{A \times B})$ is asymptotically χ^2-distributed with $df = (p–1)(q–1)$.

Optics of the bridge

Table 2. F_N test for rank-transformed data (optics).

Source of variation	F_N	df	P
T_A	64.87	1	< .01
T_B	2.02	1	< .16
$T_{A \times B}$	2.02	1	< .16
total	70.91	3	< .01

The main effect *A* (direct instruction vs. computer simulation) was significant at the α level of 0.05 ($F_N(T_A)$ = 64.87, $p < .01$). The corresponding H_0^A was rejected in favor of H_1^A: Direct instruction is superior to computer simulation with respect to the optics of the bridge.

The main effect *B* (class 9a vs. class 9b) was not significant at the α level of 0.05 $F_N(T_B)$ = 2.02, $p < .16$). The corresponding H_0^B was not rejected: Class 9a and class 9b do not differ concerning the optics of the bridge.

The interaction effect *A × B* (instructional methods × class) was not significant at the α level of 0.05 ($F_N(T_{A \times B})$ = 2.02, $p < .16$). The corresponding $H_0^{A \times C}$ were therefore not rejected: Direct instruction and computer simulation do not differ concerning the optics of the bridge in relation to the two classes.

Material usage for the bridge

Table 3. F_N test for rank-transformed data (material usage).

Source of variation	F_N	df	p
T_A	76.79	1	< .01
T_B	3.07	1	< .08
$T_{A \times B}$	3.07	1	< .08
total	82.93	3	< .01

The main effect *A* (direct instruction vs. computer simulation) was significant at the α level of 0.05 ($F_N(T_A)$ = 76.79, $p < .001$). The corresponding H_0^A was rejected in favor of H_1^A: Direct instruction is superior to computer simulation with respect to material usage for the bridge.

The main effect *B* (class 9a vs. class 9b) was not significant at the α level of 0.05 $F_N(T_B)$ = 3.07, $p < .08$). The corresponding H_0^B was not rejected: Class 9a and class 9b do not differ concerning the material usage for the bridge.

The interaction effect *A × B* (instructional methods × class) was not significant at the α level of 0.05 ($F_N(T_{A \times B})$ = 3.07, $p < .08$). The corresponding $H_0^{A \times C}$ were therefore not rejected: Direct instruction and computer simulation do not differ concerning the material usage for the bridge in relation to the two classes.

4. Discussion

The main result of the present study is that the research hypothesis – in engineering education (grade 9, secondary school) direct instruction performs better than computer simulation with respect to teaching *bridge construction* – is restrained.

Regarding questions 1 and 3, the findings show a clear picture to introduce new learning content by the two instructional methods. The introduction to bridge construction with direct instruction was much more effective than the introduction with computer simulation both on the optics of the bridge and on the material usage for the bridge.

Regarding question 2, the following can be said: The students' learning outcome in both classes was almost equal. The reason for this is the relatively uniform content. Differences between the classes resulted only for the above mentioned interaction of instructional method and class with respect to material usage.

The results specialize the empirical findings on direct instruction in the literature as pointed out by Hattie[1] as well as by Honebein and Honebein [29]: Learning outcome with direct instruction is higher than those achieved with computer simulation in bridge construction bridge. For other areas of engineering, the results obtained to use

96

computer simulation, cannot be generalizedfor electrical engineering [30] or the clothing design [31]. For these two areas, the empirical results favor computer simulation as a method in engineering education.

The results of the study 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 in more than one school by using multilevel models (see [32, 33]). In such models, further instructional methods should be included, whose evaluation will provide important insights for engineering.

5. Conclusions

In comparison with direct instruction,computer simulation has performed much worse. The conclusion that computer simulations are not applicable in engineering lessons, however, would be premature. As interviews with the students have shown, computer simulation could be very suitable especially for motivational aspects.

Direct instruction and computer simulation can be positioned in the context of specific learning theories: Direct instruction in the context of the behavioristic learning theory, computer simulation with respect to constructivist learning theory. Thus, the following additional recommendations can be made for direct instruction engineering lessons from a behavioristic perspective: Associations of learning tasks with positive events, adequate use of positive and negative amplifiers, use of models for desired behaviors [34, chapter 7].

For computer simulation in the context of the constructivist learning theory, the following recommendations should be included in engineering lessons: Emphasizing the value of stimulation and encouragement, promoting self-directed learning (self-motivation, learning techniques, self-test) [34, chapter 10].

Some important research lines can be deduced, which should be addressed in more extensive research projects of engineering education. The results in this study showed that instructional methods for engineering education can be supplemented with recommendations from the literature on learning theories. To derive even more benefit from the learning theories, (1) new instructional methods for engineering education should be developed that consistently build on the findings of the learning theories, (2) new instructional methods for engineering education should be developed that address the learning processes discussed by the learning theories (e.g. knowledge construction, knowledge integration, knowledge transfer), and (3) evaluating new instructional methods for engineering education in concrete classroom settings. Importantsuggestions for these three research lines can be obtained from current findings in neurodidactics, such as intelligent practice, selective learning access, the importance of emotions for learning [35, 36].

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