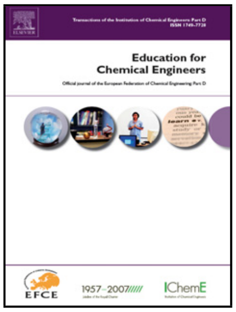

The Effect of Two Instructional Methods on Learning Outcome in Chemistry Education: The Experiment Method and Computer Simulation

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PII: S1749-7728(19)30072-7

DOI: https://doi.org/10.1016/j.ece.2019.09.001

Reference: ECE 219

To appear in: *Education for Chemical Engineers*

Received Date: 21 June 2019

Revised Date: 20 September 2019

Accepted Date: 26 September 2019

Please cite this article as: Zendler A, Greiner H, The Effect of Two Instructional Methods on Learning Outcome in Chemistry Education: The Experiment Method and Computer Simulation, *Education for Chemical Engineers* (2019), doi: https://doi.org/10.1016/j.ece.2019.09.001

The Effect of Two Instructional Methods on Learning Outcome in Chemistry Education: The Experiment Method and Computer Simulation

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Highlights

- *Comparison of two instructional methods for chemistry education by using an experimental design*
- *The comparison of the two instructional methods shows that lessons using the experiment method and computer simulations perform similar with respect to observation and application knowledge*
- *The findings supported the view of STEM teachers that computer simulation is as appropriate as the experiment method for some knowledge processes*
- *The findings are relevant to developing new instructional methods for chemistry education based on learning theories*

Abstract

This study contributes 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. All three questions represent challenges to general education and education in individual subjects. This study focuses on the empirical examination of learning outcome in chemistry education with respect to two instructional methods: the experiment method and computer simulation. An SPF-2x2•2 design is used to control instructional method, trial and class context. Learning outcome on reactions of metals is assessed. The empirical findings show that learning with computer simulation performs similar to the experiment method.

Keywords

Chemistry education, instructional methods, experiment method, computer simulation, experimental study, learning outcome.

1. Introduction

This study contributes 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. All three questions represent challenges to general education and education in individual subjects

The wide range of instructional methods is almost incomprehensible. The *Center for Teaching and Learning* (2019) 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 method which also represents the conceptual starting point for this study 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 and Hader-Popp, 2007, p. 3)

1.1. Literature Review

1.1.1. Empirical findings on the effectiveness of instructional methods

Empirical findings on the effectiveness of learning are numerous. In his compilation of 800 metaanalyses, into which more than 50,000 studies were included, Hattie (2009) provides information on the influences on learning with respect to six domains: contributions of the person learning, the parental home, the school, the teacher, the curricula and teaching. In particular, the domain of teaching (Hattie, 2009, chapters 9 and 10) provides information on the effectiveness of instructional methods/approaches.

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).

The experiment method and computer simulation are two instructional methods for which a number of empirical findings are available. For the experiment method, Hattie (2009) cites 4 meta-analyses and 205 individual studies, for computer simulation 8 meta-analyses and 361 individual studies. According to Hattie (2009) mean effect size for the experiment method (including discovery learning) is d = .42, effects in biology (d = .30) and physics (d = .27) are higher compared to chemistry (d = .10); for computer simulation, on the other hand, the effect size is d = .33.

The experiment method is often used in science education; learning effects are higher for process skills (d = .40) than for contents (d = -.26) (see Shymanskyet al., 1990). These results are confirmed by Bangert-Drowns and Bankert (1990), who report major effects in terms of critical thinking (d = 1.09).

For computer simulation, the empirical findings are not uniform. VanSickle (1986) reports that computer simulation has little advantage over traditional instructional methods. Learning effects for the development of attitudes have either been shown (VanSickle, 1986) or disproved (LeJeune, 2002). For natural science subjects, LeJeune (2002) showed that learning effects affect "deeper thinking", e.g. the ability to learn scientific facts or understand scientific processes.

1.1.2. Assessment of instructionl methods by STEM teachers

The heat map seen in Fig. 1 shows the assessment of 20 methods in terms of six knowledge processes by STEM teachers. It contains visualized means for the six knowledge processes of *build, process, apply, transfer, assess*, and *integrate* (Zendler et al. 2018). The heat map also contains the grand means of the knowledge processes for the instructional methods. The instructional methods are sorted in accordance with these grand means.

Fig. 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 five additional instructional methods: learning tasks, discovery learning, project work, direct instruction, and models method. Especially, Fig. 1 illustrates that the experiment method was highly assessed, especially for *process*, whereas computer simulation for *apply* and *transfer*.

In a more detailed observation the heat map reveals that problem-based learning is distinguished by high values (> 3.50) for almost all knowledge processes. Learning tasks is characterized by high values (> 3.50) for the knowledge processes of *process* and *apply*. Discovery learning demonstrates high values (> 3.50) for the knowledge process *build*. Particularly high values (> 4.00) for the knowledge process *build* are shown by direct instruction, which additionally has relatively high values (> 3.00) for the knowledge processes of *process* and *apply*. Project work is notable for relatively high values (> 3.50) with the knowledge processes *transfer* and *assess,* direct instruction for the high values (> 3.50) with *process.* The following instructional methods in the heat map are also noteworthy: The models method due to its relatively high values in the knowledge process *apply*, programmed instruction due to its relatively high values in the knowledge processes *build* and *process*, learning stations due to its relatively high values in the knowledge process of *process.*

The following instructional methods had relatively low values in all of the knowledge processes (< 3.00): learning by teaching, case study, the jigsaw method, concept mapping and the Leittext method. Web quest, reciprocal teaching and the portfolio method were rated as relatively poor (< 2.50) in all of the knowledge processes.

1.1.3. Instructional methods in chemistry education

The study of instructional methods for chemistry lessons has a long tradition. They go back to Ahmann (1949), who compared several methods favoring the so-called recitation-laboratory method. Castleberry et al. (1973) presents the results of a study involving the use of computer-based techniques in a general chemistry course with suggestions for using computers. Jackman, Moellenberg, and Brabson (1987) studied the effectiveness of instructional approaches on college chemistry laboratory achievement learning; computer simulation was the most effective.

The search through recent English-language magazines on chemical education (Journal of Chemical Education, Frontiers of Chemical Science and Engineering, Education for Chemical Engineers, Chemistry Education Research and Practice, Education in Chemistry) provided findings related to instructional methods in regard to traditional and computer-assisted learning in teaching acids and base (Morgil et al., 2005), to the effectiveness of inquiry-based activities (Prince et al., 2009), to using concept maps as instructional materials to foster the understanding of the atomic model (Aguia and Correia, 2016). Current and Kowalske (2016) reported on the effectiveness of problem-based learning when building models of different chemical structures. Much evidence shows that instruction actively engaging students with learning materials is more effective than traditional, lecture-centric instruction (Rau et al., 2017). Finally, Azizan et al. (2018) report on improving teamwork skills and enhancing deep learning via development of board game using cooperative learning.

There has been less investment in evaluating what features of simulations best support chemistry learning for a diverse range of learners (Plass et al., 2009). At high school level, Plass et al (2012) study the learning effectiveness of computer simulation in two schools of rural Texas and urban New York on kinetic molecular theory; they report on positive effects. Tatli et al. (2013) show that students of a ninth-grade classroom recognize laboratory equipment in a computer simulation environment. Doneely et al. (2013) present case studies of four science teachers using a virtual chemistry laboratory with their students. Recently, Davenport et al. (2018) demonstrated the learning effectiveness of ChemVLab with a sample of 1,400 high school students in a pre-post study.

1.2. The Two Instructional Methods

As the studies show, computer simulation has long been recognized as an instructional method for chemistry lessons. On the other hand, the experiment method has a long tradition when teaching chemistry. In the following, these methods are described in more detail in order to be able to ask the research question.

1.2.1. Experiment Method

The basic structure of this instructional method (see Fig. 2) is as follows: (1) *Viable phenomenon.* The teacher confronts the students with a scientifically viable phenomenon. (2) *Hypothesis formation.* In consultation with the teacher the students form cause-and-effect hypotheses regarding the phenomenon based on the current state of knowledge. (3) *Isolation of variables.* In consultation with the teacher the students define the factors which are to be examined for their effects on the dependent variables – with the exclusion of disruptive influences. (4) *Execution.* With the help of the teacher, the students conduct the experiment, collect data, and document the course of an experiment. (5) *Evaluation.* In consultation with the teacher the students evaluate the experiment and examine the validity of the hypotheses. (6) *Discussion.* The teacher discusses the findings with the students with a view to follow-up experiments.

Examples of the experiment method with chemistry contents are numerous and are available in textbooks for chemistry lessons (e.g. ACS, 2017; Bäuerle and Bergau, 2009), on the websites of AACT (2019) and lehrer-online (2019).

1.2.2. Computer Simulation

This instructional method (see Fig. 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 which interventions they want to introduce 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.* The students propose new hypotheses and repeat the steps 3 to 6.

Kranz (2012) describes exmples of the method in chemistry education: Simulations of equilibrium reactions and visualizations of organic molecules with structural and formula editors (e.g. *Isis draw, Chem draw, ChemSketch*). The University of Boulder (2019) presents more than 50 interactive simulations in the two categories General Chemistry and Quantum Chemistry. On the website of Crocodile Clips (2019) teaching examples are described using the simulation software Yenka.

1.2.3. Positioning of Experiment Method and Computer Simulation

By using the frame of reference by Wiechmann and Wildhirt (2015), which consists of three educational dimensions (*instruction control, mediation style,* and *lesson design)*, we positioned the experiment method and computer simulation (see Fig. 4). With regard to lesson design and mediation style, both methods are similarly classified. They are very discovery-oriented with respect to mediation style and planned concerning lesson design. Both instructional methods are different in terms of instruction control: The experiment method is more teacher-controlled than computer simulation. Because of this difference, it must be assumed that the cognitive load (Tversky et al., 2006) – amount of mental activity performed by the working memory with a specific task (Akaygun, 2013) – is lower for the experiment method than for computer siumulation.

1.3. 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. *Reactions of metals* are one such topic. They contribute to content and process concepts of chemistry education. Moreover, they are consistent with the requirements of educational standards for chemistry education (AACT, 2019; ACS, 2017; KMK, 2004), and thus receive their educational legitimacy. When selecting the learning content, it was considered that only content that could easily be used as a student experiment was shortlisted: it should neither be dangerous nor life-threatening for the students.

1.3.1. Burning of metals

Metals react with oxygen from the air. This reaction is different for individual metals. Alkali metals are very violent and readily oxygenated, i.e. they burn. In contrast, some precious metals (silver, gold, and platinum) do not react with oxygen at all. The burning of a metal is accompanied by a flame phenomenon. The release of energy accompanied by light and heat is called an exothermic reaction (see Cogill et al., 2009b).

1.3.2. Reactions of metals with hydrochloric acid

As with burning, some metals react better (stronger) and some metals worse or not at all with hydrochloric acid. Again, the alkali metals react most violently with hydrochloric acid, precious metals not at all. The reaction of a metal with hydrochloric acid is a redox reaction: salt and hydrogen are produced (see Cogill et al., 2009a).

1.4. Research Questions

The experiment method and computer simulation are two instructional methods, which were classified similarly in the two dimensions of mediation style and lesson design. However, they are different in instructional control.

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 Fig. 1). In the opinion of the STEM teachers the experiment method is well suited to the knowledge processes of *process*, while computer simulation is suitable to the knowledge process of *apply* and *transfer*. Hattie (2009), on the other hand, found in his meta-analyses that the two methods are more or less effective.

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 chemical 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 are when used in authentic chemistry recitations.

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

(1) Experiment method vs. computer simulation: Which instructional method performs better with respect to learning outcomes on *reactions of metals*? 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 outcomes when the experiment method or computer simulation are used as instructional methods? 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 also to be considered.

(3) Knowledge types: Learning outcome is a complex construct that can only be grasped through the interplay of several variables. Thus, the question arises as to whether learning outcome differs by using the experiment method and computer simulation, particularly with respect to prior, observation, and application knowledge.

The following research hypothesis is linked to these three questions:

"In chemical education (grade 8, secondary school) the experiment method performs better than computer simulation with respect to teaching *reactivity of metals.”*

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. Methodology

2.1. Study Design

Experimental design. An SPF-2x2•2 design (Split Plot Factorial design, 3-factor design with repeated measure for factor *B,* see Fig. 5) is used to test the research hypothesis (Kirk, 2012).

Independent variables. Factor A represents the instructional methods: a_1 = experiment, a_2 = computer simulation. Factor B represents time: b_1 = before lesson, b_2 = after lesson. Factor C represents classes: c_1 = class 8c, c_2 = class 8d. s_1, …, s_{4n} represent students.

Dependent variables. Two classroom assessment tests – one for trial b_1 (burning of metals) and one for trial b_2 (reactions of metals) – on prior, observation, and application knowledge were used to assess student knowledge. The assessment is based on scores: for prior knowledge the maximum score is 4, for observation knowledge 5.5, and for application knowledge 19. To assess the prior and observation knowledge short items were used to call for students a tic, word, phrase, or sentence. Items for prior knowledge include questions that students had learned from previous chemistry lessons. They serve to determine whether the students have the same level of basic chemistry knowledge. To assess the application knowledge, short items again were used, in addition to essay items, eliciting student response on one or more paragraphs.

The answers to the items are constructed reponses of the students. For the scoring of the individual items the response time of the students was used, which was estimated during the construction of the items. The appendix contains the two assessment tests with all items, the correct answers and the scoring of the items (for the development of classroom assessment tests, see Popham 2014; Lane, 2016).

Power analysis. The sample size for the SPF-2x2•2 design (Mueller and 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 ($\Delta = 0.80$) in relation to the dependent variable are classified as significant; the significance level is $\alpha = 0.05$. 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, 2019) with respect to ε-corrected F-Tests (Mueller and Barton, 1989; by Mueller et 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 chemical education (grade 8, secondary school) the experiment method performs better than computer simulation with respect to teaching *reactivity of metals* operationalized by item ratings with respect to (1) prior knowledge, (2) observation knowledge, and (3) application knowledge.”

2.2. Procedure

For the study, two classes of grade 8 with a total of 45 students from the junior high school Plochingen were selected. Permits were obtained from the parents of the participants in order to carry out the study. The following criteria were important for the selection of these classes: (1) chemistry is offered in both classes, (2) both classes can be instructed with the same lesson, (3) the lessons had the same time frame conditions.

For the study, the school's half-class organization was used: The two selected classes were already divided into four equal groups. 22 students were taught by the experiment method, 23 students were instructed by computer simulation. In class 8c, 10 students were taught by the experiment method and 12 students by computer simulation. In class 8d, 12 students were instructed by the experiment method and 11 students by computer simulation. The groups were divided in such a way that equal-performance groups are formed. In carrying out this study, the chemistry room is used for the experiment method and the computer room for computer simulation. The students were taught in German. The students had previously no experience with the two instructional methods.

To carry out the computer simulation, Yenka by Crocodile Clips (Crocodile Clips 2019) was used. Yenka offers users the opportunity to conduct experiments in a virtual lab. The user can choose from a wide range of ready-made models or even create models. Fig. 6 shows typical sections of the simulation software Yenka Chemistry (see Crocodile Clips 2019).

The lesson was conducted by a female teacher (24 years old). who has undergone intensive training in instructional methods for chemistry education. Both lessons with the experiment method and computer simulation were planned by this teacher; all materials were developed by this teacher. The lesson length was 90 minutes.

To assess student learning outcome, two classroom tests (burning of metals, for reactions of metals with hydrochlorid acid) have been used. The tests have been developed, administered and evaluated by the teacher who did the teaching. The processing time for the tests was 15 minutes.

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 1.2.1. and 1.2.2.). In the beginning of each lesson, students were shown two short videos as an introduction to the experiment of the lessons and for further motivation. In the videos, the two experiments of *burning metals* and *reactions of metals with hydrochloric acid* were carried out with respect to sodium and gold.

2.3. Procedure for Data Analyses

In analyzing our empirical data (see Appendix A-2), the following procedure is carried out: (1) First, we analyze the data descriptively. (2) Then, we conduct three-way ANOVAs with repeated measures in accordance with the SPF-2x2•2 split-plot design (see Winer et al., 1991, chapter 7).

Data analyses were conducted using SPSS 24.0; the power analysis was computed with PASS 15 (NCSS, 2019).

3. Results

3.1. Descriptive Analyses

The results of learning outcome, including the class context, are illustrated in Fig. 7, 8, and 9 (Original Data, see Appendix A-2). They show means as well as 95% confidence intervals for learning outcome with respect to prior knowledge, observation knowledge, and application knowledge.

3.1.1. Prior knowledge

From Fig. 7, it is noticeable that the instructional methods performed the same concerning prior knowledge. Class 8d performed slightly better when burning metals. The learning outcomes are relatively homogeneous for both instructional methods; this is shown by the 95% confidence intervals.

3.1.2. Observation knowledge

With respect to observation knowledge (see Fig. 8) the results are inconsistent. Class 8c was somewhat more effective for burning metals. In class 8d, the experiment method was more effective for *burning metals* as well as for *reactions of metals* with hydrochloric acid.

3.1.3 Application knowledge

In the case of the application knowledge (see Fig. 9), the results are similar to those of prior knowledge: the instructional methods performed about the same level of both trials.

3.2. Statistical Analyses

To examine whether the experiment methods differs from computer simulation with respect to learning, we formulated seven statistical hypotheses, which were tested at the significance level of α = 0.05.

Statistical hypotheses. The seven null hypotheses were as follows:

i) the means (learning outcome with respect to prior knowledge, observation knowledge, application knowledge) of the instructional method μ_1 under factor level a_1 (experiment method) are equal or less compared to the means of the instructional methods μ_2 under the factor level a_2 (computer simulation), such that:

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

ii) the means (learning outcome with respect to prior knowledge, observation knowledge, application knowledge) of the instructional method μ_1 under factor level b_1 (burning metals) are equal or greater compared to the means μ_2 under b_2 (reactions of metals with hydrochloric acid), such that:

$$H_0^B : \mu_1 \geq \mu_2 \quad (H_1^B : \mu_1 < \mu_2);$$

iii) the means (learning outcome with respect to prior knowledge, observation knowledge, application knowledge) of the instructional method μ_1 under factor level c_1 (class 8c) and μ_2 under c_2 (class 8db) are equal, such that:

$$H_0^C : \mu_1 = \mu_2 \quad (H_1^C : \mu_1 \neq \mu_2);$$

iv) the means (learning outcome with respect to prior knowledge, observation knowledge, application knowledge) of the instructional methods $\mu_{1\bullet1}$, $\mu_{1\bullet2}$, $\mu_{2\bullet1}$, $\mu_{2\bullet2}$ under the 2 • 2 levels of factor combinations $A \bullet B$ are equal, such that:

$$H_0^{A\bullet B} : \mu_{1\bullet1} = \mu_{1\bullet2} = \mu_{2\bullet1} = \mu_{2\bullet2} \quad (H_1^{A\bullet B} : \mu_{1\bullet1} \neq \mu_{1\bullet2} \neq \mu_{2\bullet1} \neq \mu_{2\bullet2});$$

v) the means (learning outcome with respect to prior knowledge, observation knowledge, application knowledge) of the instructional methods $\mu_{1\times1}$, $\mu_{1\times2}$, $\mu_{2\times1}$, $\mu_{2\times2}$ under the 2 × 2 levels of factor combinations $A \times C$ are equal, such that:

$$H_0^{AxC}: \mu_{1\times 1} = \mu_{1\times 2} = \mu_{1\times 2} = \mu_{2\times 2} \quad (H_1^{AxC}: \mu_{1\times 1} \neq \mu_{1\times 2} \neq \mu_{1\times 2} \neq \mu_{2\times 2});$$

vi) the means (learning outcome with respect to prior knowledge, observation knowledge, application knowledge) of the instructional methods $\mu_{1\bullet 1}$, $\mu_{1\bullet 2}$, $\mu_{2\bullet 1}$, $\mu_{2\bullet 2}$under the 2 • 2 levels of factor combinations C • *B* are equal, such that:

$$H_0^{C\bullet B}: \mu_{1\bullet 1} = \mu_{1\bullet 2} = \mu_{2\bullet 1} = \mu_{2\bullet 2} \quad (H_1^{C\bullet B}: \mu_{1\bullet 1} \neq \mu_{1\bullet 2} \neq \mu_{2\bullet 1} \neq \mu_{2\bullet 2});$$

vii) the means (learning outcome with respect to prior knowledge, observation knowledge, application knowledge) of the instructional methods $\mu_{1\times 1\bullet 1}$, $\mu_{1\times 1\bullet 2}$, …, $\mu_{2\times 2\bullet 2}$ under the 2 × 2 • 2 levels of factor combinations *A* × *C* • *B* are equal, such that:

$$H_0^{AxC\bullet B}: \mu_{1\times 1\bullet 1} = \mu_{1\times 1\bullet 2} = \ldots = \mu_{2\times 2\bullet 2} \quad (H_1^{AxC\bullet B}: \mu_{1\times 1\bullet 1} \neq \mu_{1\times 1\bullet 2} \neq \ldots \neq \mu_{2\times 2\bullet 2}).$$

Testing the statistical assumptions. For an analysis of variance (ANOVA), the data of a SPF-2x2•2 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 assumptions were not significant ($p > .05$). Thus, the data were analyzed by using ANOVAs (see Table 1, 2, 3).

3.2.1. Prior knowledge

3.3.2 Observation knowledge

3.3.3Application knowledge

The main effects *A* (experiment method vs. computer simulation) were not significant at the α level of 0.05 with respect to *prior knowledge* ($F_{1,41}$ = 0.73, $p < .40$), *observation knowledge* ($F_{1,41}$ = 0-74, $p < .40$), *application knowledge* ($F_{1,41}$ = 1.22, $p < .28$). The corresponding H_0^As were not rejected: Experiment method and computer simulation do not differ concerning learning outcome.

The main effects *B* (burning metals vs reactions of metals) were significant at the α level of 0.05 for *prior knowledge* ($F_{1,41}$ = 35.40, $p < .01$), and *application knowledge* ($F_{1,41}$ = 32.64, $p < .01$). The corresponding H_0^Bs were rejected: *Elementary* and *application knowledge* were higher for burning metals than for reaction of metals with hydrochlorid acid.

The main effects C (class 8c vs. class 8d) were not significant at the α level of 0.05 with respect to each knowledge type. The corresponding H_0^Bs were not rejected: Class 8c and class 8c do not differ concerning knowledge types.

The interaction effects $A \bullet B$ (instructional methods • trial) were not significant at the α level of 0.05 for with respect to each knowledge type. The corresponding $H_0^{A\bullet B}$s were not rejected: The experiment method and computer simulation do not differ in terms of knowledge types in relation to trial.

The interaction effects $A \times C$ (instructional methods × class) were not significant at the α level of 0.05 with respect to *kowledge types*. The corresponding $H_0^{A\times C}$s were therefore not rejected: The experiment method and computer simulation do not differ in terms of knowledge types with respect to the two classes.

The interaction effects $C \bullet B$ (class • trial) were not significant at the α level of 0.05 for with respect to each *knowledge type*. The corresponding $H_0^{C\bullet B}$s were not rejected: The two classes are not different in terms of knowledge types in relation to trial.

The interaction effects $A \times C \bullet B$ (instructional method × class • trial) was significant at the α level of 0.05 with respect to *observation knowledge* ($F_{1,41} = 4.25$, $p < 0.05$): The corresponding $H_0^{AxC\bullet B}$ was rejected: Experiment method and computer simulation differ concerning *observation knowledge* in relation to the two classes and trial.

4. Discussion

The main result of the present study is that the research hypothesis – in chemical education (grade 8, secondary school) the experiment method performs better than computer simulation with respect to teaching *reactivity of metals* – cannot be maintained.

Effectiveness of instructional methods. With regard to questions 1 and 3, the experiment method and computer simulation are effective with respect to learning outcome on *reactions of metals*. The comparison of the two instructional methods shows that the experiment method and computer simulations performed similar.

Differences were found in the two trials (burning of metals and reactions of metals with hydrochloric acid). In particular, prior knowledge with reactions of metals with hydrochloric acid was lower. In the observation tasks, the interaction effect between instructional method, class, and trial is interesting: for class 8c the experiment method is superior to computer simulation.

Class differences. Regarding question 2, the following can be said: The student 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 triple interaction of instructional method, class, and trial.

Reflection. With the experiment method, the trials ran without major incidents, since the students know the general procedure and the rules from previous experiments. Concerning computer simulation, the encouragement "just start experimenting" led students to experiment in some unreflective way. The reason for this could be that the inhibition threshold to do something wrong with computer simulation is significantly lower than with the experiment method. For the teacher it is harder to keep track of which group have questions or problems.

Comparing the findings with those of others. The findings in this study correspond only partly to the results and suggestions from the relevant literature on the use of the experiment method and computer simulation for chemistry education.

For computer simulation, the following can be stated: (1) It seems that this method could have the significance that is sometimes attributed to for chemistry education (Avramiotisab and Tsaparlis, 2013; Hawkins and Phelps, 2013; Davenport et al., 2018), especially when supported by appropriate guidance (Chamberlain et al, 2014), (2) the STEM teacher assessment of the method in the five knowledge processes (build, process, apply) can only be confirmed to a limited extent (Zendler et al. 2018). In contrast to computer simulation, some effects with the experiment method can be confirmed and partly exceeded, in particular, the method has performed better than the STEM teacher assessment would have allowed, especially for the knowledge process of *apply* (Zendler et al. 2018), The reason for this may be the lower cognitive load of the experiment method in comparison with computer simulation (Tversky et al., 2006; Akaygun and Jones, 2013).

Limitations. 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 (Goldstein, 2010). In such models, further instructional methods should be included, whose evaluation will provide important insights for teaching chemistry.

5. Conclusions

Computer simulation and the experiment method can be seen as complementary instructional methods. For practical work and problem solving chemistry activities, the experiment is of central importance for acquiring relevant competences (Tsaparlis, 2009, Johnstone and Al-Shuaili, 2001, Avriamotis and Tsaparlis, 2013). In addition, there is content for which it has been shown that it should be taught in any case using the experiment method. Examples are: electron flow in aqueous solutions (Sanger and Greenbowe, 2000), sodium chloride dissolving (Kelly and Jones, 2007), oxidation-reduction reaction (Rosenthal and Sanger, 2012).

Computer simulation is advantageous, especially for students who are less familiar with experimenting. Often students dare not even turn on the burner, let burn a substance, or let react with another. Here, computer simulation can help students to get routine work done. Furthermore, computer simulation can be consulted for illustrative purposes. This is not necessarily possible with a "normal" experiment due to time and cost.

The experiment method and computer simulation can be positioned in the context of specific learning theories: The experiment method in the context of the cognitivist learning theory, computer simulation with respect to constructivist learning theory. Thus, the following additional recommendations can be made for chemistry lessons based on the experiment method from a cognitivist perspective: Ensuring learners attention to the lesson, helping learners to link information with prior knowledge, organizing learning materials in a clear and organized manner (Eysenck and Keane, 2015, Chapter 8).

For computer simulation in the context of the constructivist learning theory, the following recommendations should be included in chemistry lessons: Emphasizing the value of stimulation and encouragement, promoting self-directed learning (self-motivation, learning techniques, self-test) (Eysenck and Keane, 2015, Chapter 10).

Some important research lines can be deduced, which should be addressed in more extensive research projects of chemistry education. The results in this study showed that instructional methods for chemistry 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 chemistry education should be developed that consistently build on the findings of the learning theories, (2) new instructional methods for chemistry 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 chemistry education in concrete classroom settings. Important suggestions 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 (Mareschal and Butterworth, 2013; Collins, 2015).

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

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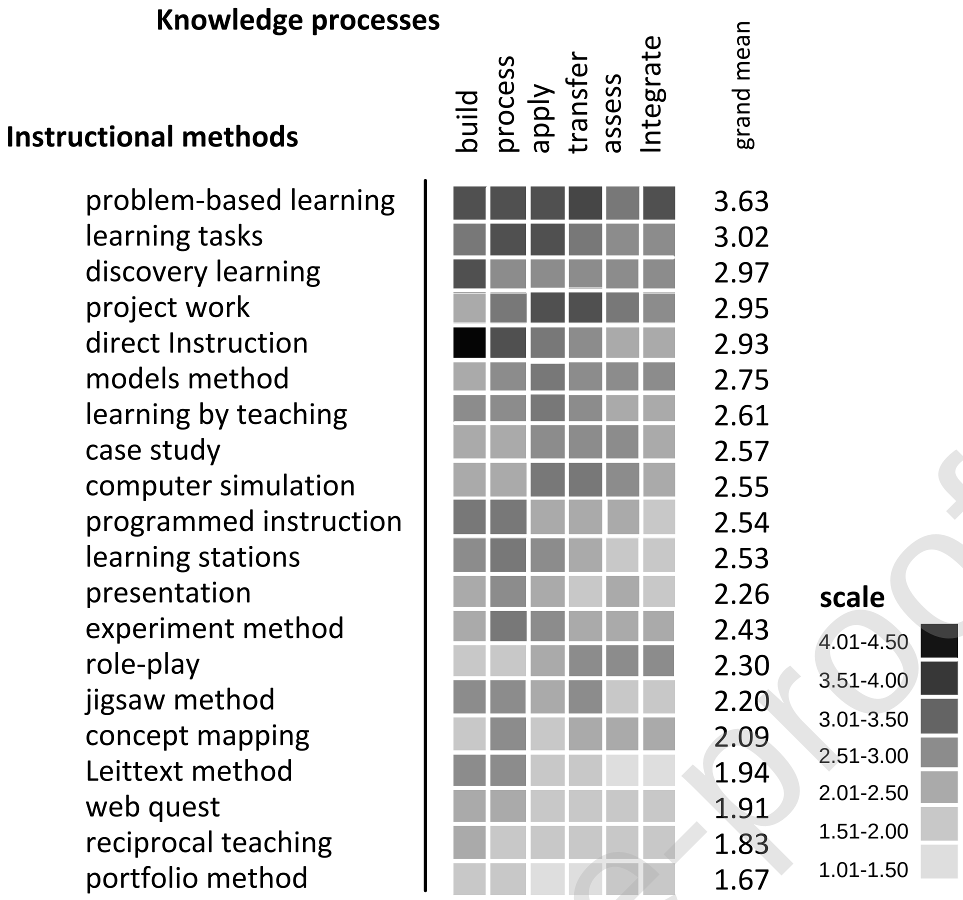


Fig. 1. Means of the instructional methods visualized for the knowledge processes (adapted from Zendler et al. 2018)

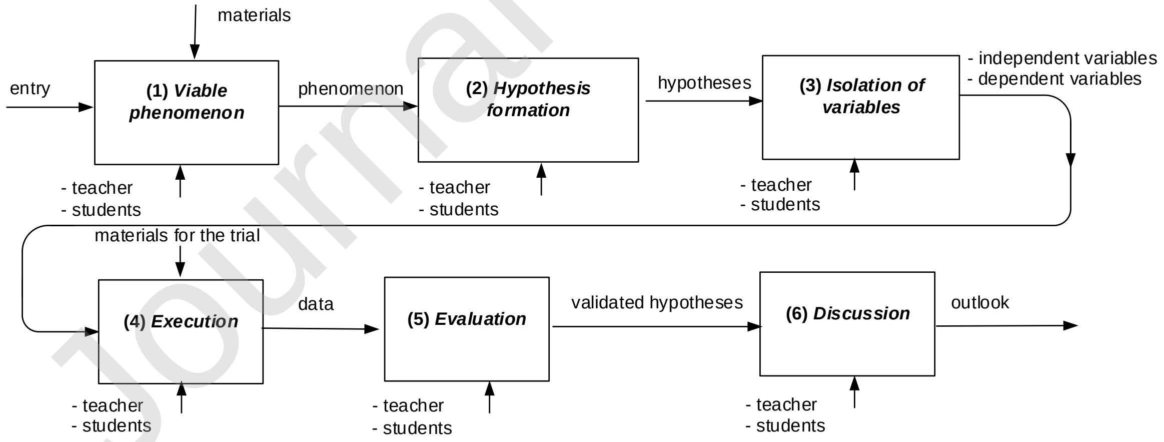


Fig. 2. Process model of the experiment method (see Zendler et al. 2018)

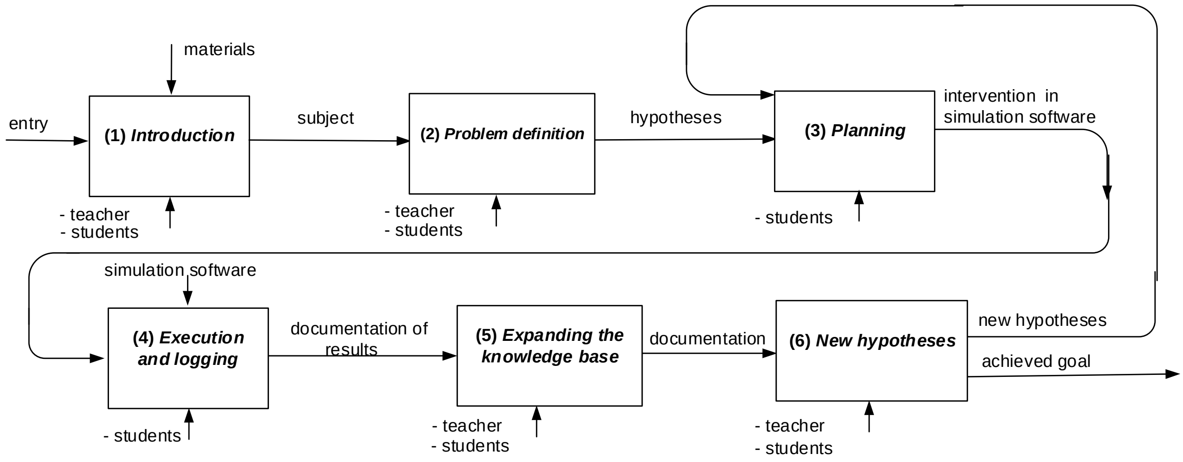


Fig. 3. Process model of computer simulation (see Zendler et al. 2018)

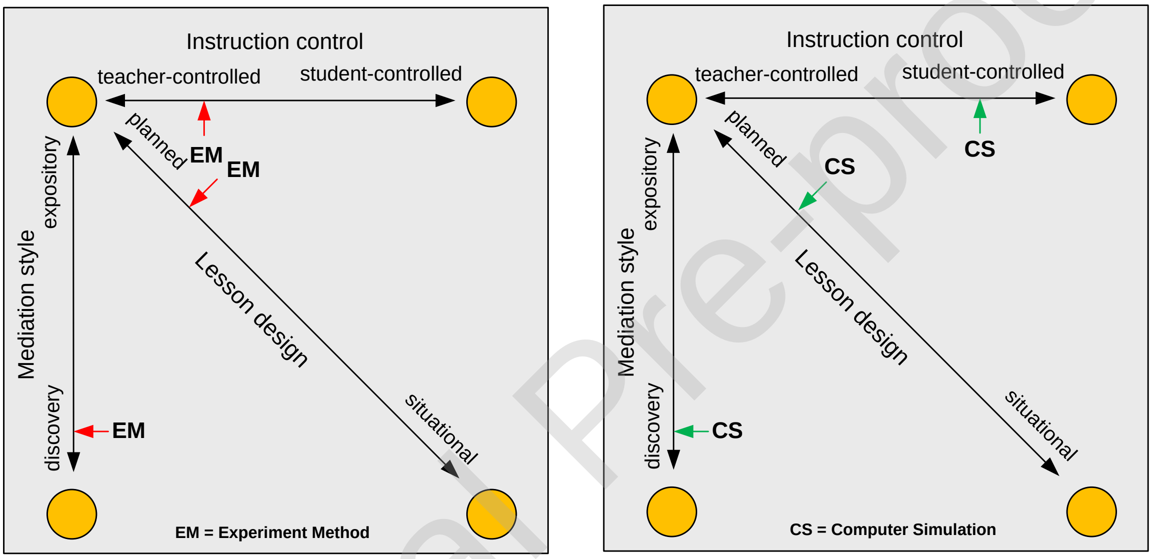


Fig. 4. Positioning of the two instructional methods (based on Wiechmann and Wildhirt, but unique for experiment method and computer simulation)

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

A = Instructional methods
a_1 = Experiment method
a_2 = Computer simulation

B = Trial
b_1 = Burning of metals
b_2 = Reactions of metals

C = Class
c_1 = 8c
c_2 = 8d

Fig. 5. Layout of the SPF-2x2•2 design

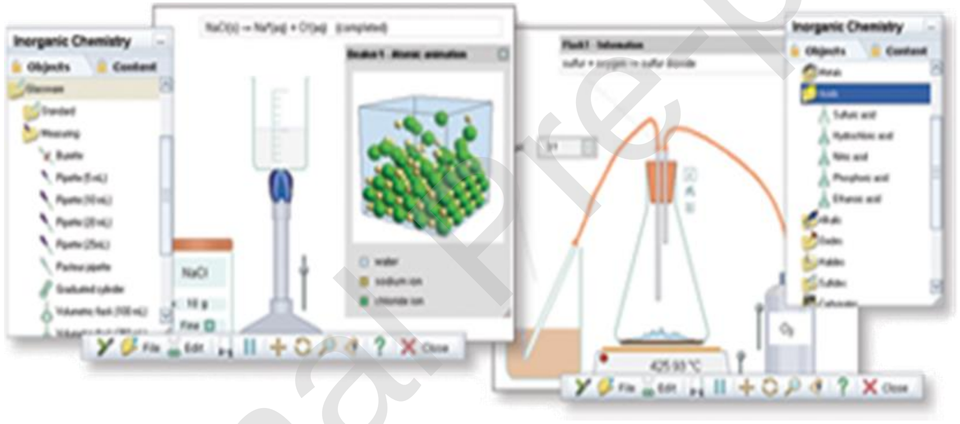


Fig. 6. Simulation software Yenka Chemistry (Courtey by © Sumdog Ltd [2019]. All Rights Reserved)

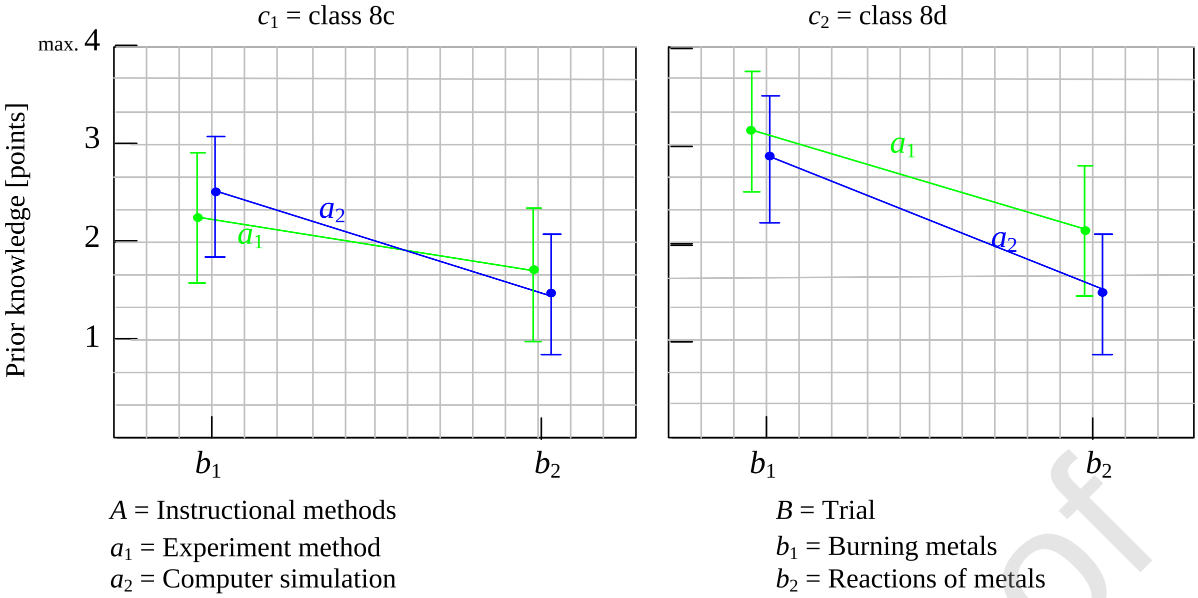


Fig. 7. Means and 95% confidence intervals for *prior knowledge*

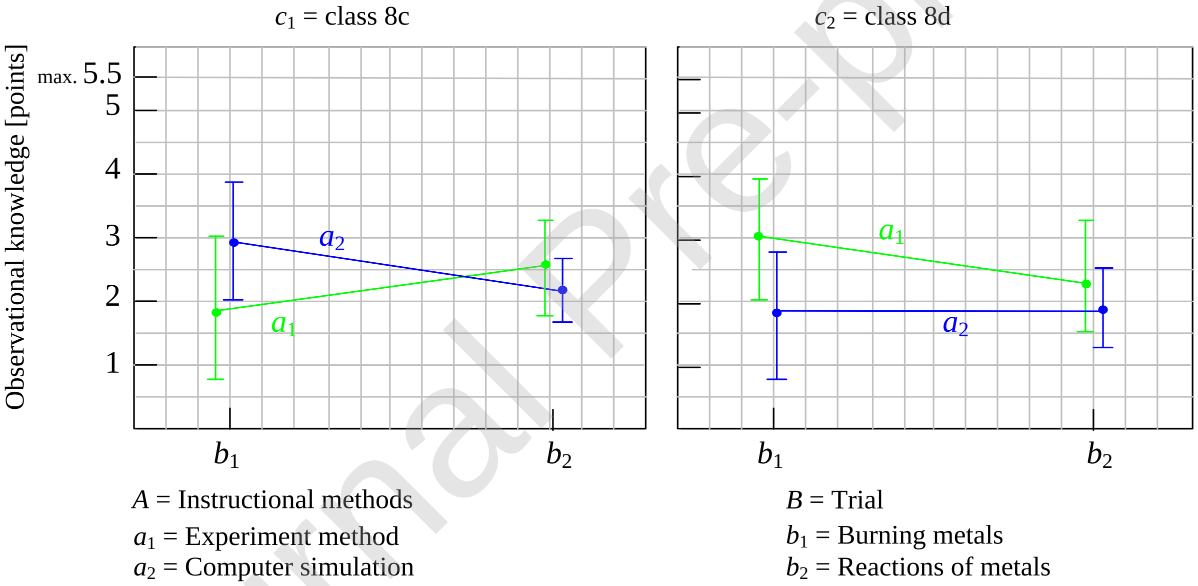


Fig. 8. Means and 95% confidence intervals for *observation knowledge*

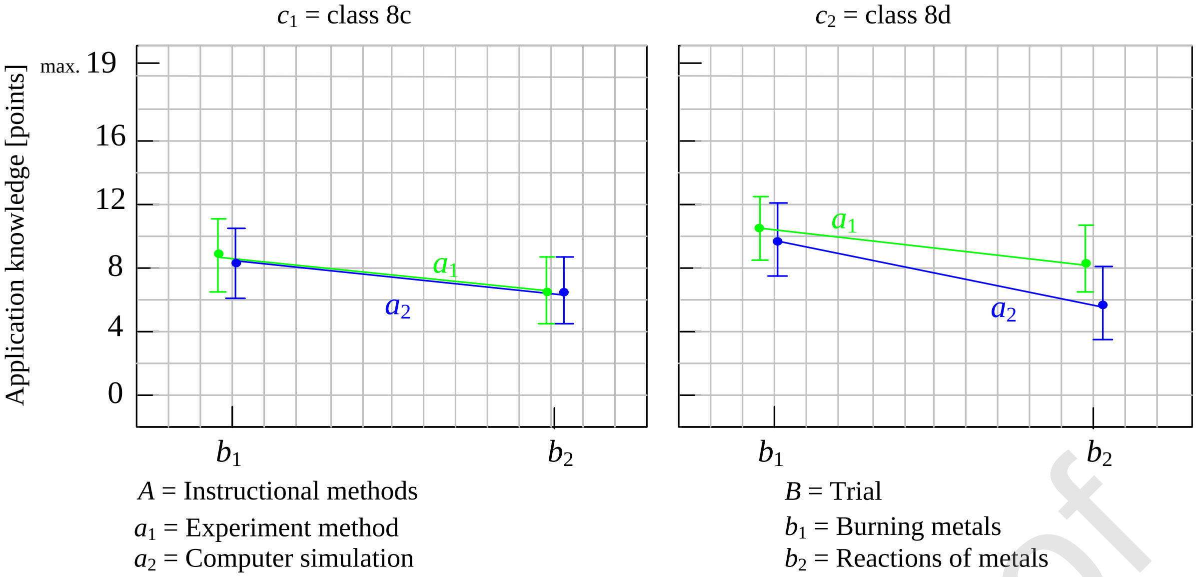


Fig. 9. Means and 95% confidence intervals for *application knowledge*

Table 1. ANOVA for *prior knowledge*

Source of variation	*SS*	*df*	*MS*	*F*	*p*	η^2	
between subjects							
A (instructional method)	1.10	1	1.10	0.73	< .40	.018	
C (class)	4.10	1	4.10	2.76	< .10	.063	
A × C	1.68	1	1.68	1.13	< .29	.027	
error	60.95	41	1.49				
within subjects							
B (trial)	21.04	1	21.04	35.40	< .01	.463	
A • B	.76	1	.76	1.28	< .27	.030	
C • B	1.11	1	1.11	1.86	< .18	.043	
A × C • B	.004	1	.004	.01	< .94	.001	
error	24.37	41	.59				

Table 2. ANOVA for *observation knowledge*

Source of variation	*SS*	*df*	*MS*	*F*	*p*	η^2	
between subjects							
A (instructional method)	1.09	1	1.09	0.74	< .40	.018	
C (class)	0.80	1	0.80	0.37	< .55	.009	
A × C	6.85	1	6.85	3.19	< .08	.072	
error	88.24	41	2.15				
within subjects							
B (trial)	1.15	1	1.15	.71	< .40	.017	
A • B	.82	1	.82	.51	< .49	.012	
C • B	.73	1	.73	.45	< .50	.011	
A × C • B	6.87	1	6.87	4.25	< .05	.094	
error	66.24	41	1.62				

Table 3. ANOVA for *application knowledge*

Source of variation	*SS*	*df*	*MS*	*F*	*p*	η^2	
between subjects							
A (instructional method)	27.29	1	27.29	1.22	< .28	.029	
C (class)	25.29	1	25.29	1.15	< .29	.027	
A × C	10.71	1	10.71	.48	< .49	.012	
error	916.07	41	22.34				
within subjects							
B (trial)	171.33	1	171.33	32.64	< .01	.443	
A • B	4.93	1	4.93	.94	< .34	.022	
C • B	1.65	1	1.65	.31	< .58	.008	
A × C • B	10.15	1	10.15	1.93	< .18	.045	
error	215.20	41	5.25				

Appendix

A-1 Classroom assessment tests

Burning of metals

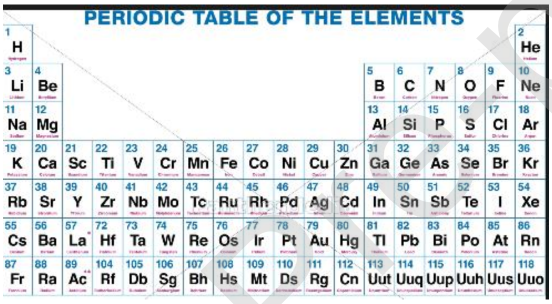
Sex: ☐ male **Age:** ____ **Class:** ____

☐ female

Item 1: List the metals used in the experiment (also the metals used in the video). [3.5 pts]

`magnesium, aluminum, copper, iron, silver, gold, sodium`

Item 2: Mark the metals used in the experiment in the periodic table of the elements (also the metals used in the video). [3.5 pts.]



Item 3: Which metal used in the experiment (with the exception of the metals from the video) reacted the most when burnt? [1 pt.]

`magnesium`

Item 4: Which metal used in the experiment (with the exception of the metals from the video) reacted least or not at all when burnt? [1 pt.]

`silver`

Item 5: Set up a number of metals for their reactivity to burning. Start with the metal that has reacted the most. In addition, put the metals used in the video into a series. [7 pts.]

`sodium magnesium aluminum iron copper silver gold`

Item 6: With which element do the metals react when burning? [0.5 pts.]

`oxygen`

Item 7: Burning produces metal oxides. For each metal, put the reaction equation in words. [7 pts.]

aluminum + `oxygen` → `aluminum oxide`
iron + `oxygen` → iron oxide
gold + `oxygen` → *`no reaction`*
copper + `oxygen` → `copper oxide`
magnesium + `oxygen` → `magnesium oxide`

silver + oxygen → *no reaction*

Item 8: Use the words given to set up a rule of the form *the … the* for burning metals. [5 pts.]

precious — binding — energy production

The more precious a metal the lower its binding to oxygen
The more precious a metal the higher its energy production
Or
The less precious a metal the higher its binding to oxygen
The less precious a metal the lower its energy production

Remarks: 1) The assessment test has ben translated from German into English for the purpose of publication. 2) Observation knowledge [maximum score 5.5]: items 1, 3, 4; Elementary knowledge [maximum score 4]: items 2, 6; Application knowledge [maximum score 19]: items 5, 7, 8; Correct responses are typed using Courier font

Reactions of metals

Sex: ☐ male **Age:** ____ **Class:** ____

☐ female

Item 1: For which metals you can observe a temperature increase and a gas evolution when reacting? [3 pts.]

magnesium, aluminum, iron

Item 2: What means a temperature increase in reactions (without using a Bunsen burner)? Name the technical term for such reactions. [2 pts.]

In these reactions, energy is produced (in the form of heat)
It is an exothermic reaction

Item 3: What kind of gas was produced and how could you test it? [2 pts.]

hydrogen
detection reaction: oxyhydrogen test

Item 4: From metals that react with hydrochloric acid under gas evolution, salts (chlorides) are formed. These dissolve in the acid and are not visible. Set up the reaction equation for these metals. [3 pts.]

magnesium + hydrochloric acid → magnesium chloride + hydrogen
aluminum + hydrochloric acid → aluminum chloride + hydrogen
iron + hydrochloric acid → iron chloride + hydrogen

Item 5: Arrange the metals for the severity of the reaction with (dilute) hydrochloric acid. Start with the metal that has reacted the most (also the metals used in the video). [7 pts.]

sodium, magnesium, aluminum, iron, copper, silver, gold

Item 6: Compare the result of this lesson with the result of the previous lesson (burning of metals). Are there any similarities or differences in the reactivity of the metals? [2.5 pts.]

sodium, magnesium, aluminum, iron react in both experiments
copper reacts when burned, but not with hydrochloric acid
silver and gold do not react in both experiments

Item 7: Use the words given to set up a rule for the reaction of metals in hydrochloric acid. [2 pts.]

hydrogen — non-precious — hydrochloric acid

Non-precious metals react with hydrochloric acid by evolution of hydrogen

Item 8: With the help of the findings from the two experiments, assign the metals to the categories of non-precious metals, semi-precious metals, and precious metal. Justify your answer. [7 pts.]

non-precious metals	**semi-precious metals**	**precious metals**
magnesium aluminum iron	copper	silver gold

sodium		

Justification:

`Sodium, magnesium, aluminum, iron react in both experiments: non-precious metals`
`Copper reacts when burned, but not with hydrochloric acid: semi-precious metal`
`Silver and gold do not react: precious metals`

Remarks: Observation knowledge [maximum score 5.5]: items 1, 6; Elementary knowledge [maximum score 4]: items 2, 3; Application knowledge [maximum score 19]: 4, 5, 7, 8; Correct responses are typed using Courier font;

A-2 Data set

The subsequent table show the obtained data sets for the SPF-2x2•2 design with n_{11} = 10 students and n_{12} = 12 of class 8c, n_{21} = 12 and n_{22} = 11 students of class 8d. From the students, data sets are available for prior knowledge, observation and application knowledge. Moreover, the tables contain means and the standard errors of the means.

Table A1. Data set for the SPF-2x2•2 design

		b_1			b_2					b_1			b_2		
		Y_1	Y_2	Y_3	Y_1	Y_2	Y_3			Y_1	Y_2	Y_3	Y_1	Y_2	Y_3
a_1c_1	s_1	3.50	5.50	14.00	2.00	3.00	11.25	a_2c_1	s_{23}	3.50	5.50	13.00	3.00	3.50	13.00
	s_2	1.00	1.50	14.50	2.00	3.50	9.50		s_{24}	2.00	2.00	7.00	2.00	1.50	3.00
	s_3	2.00	4.50	12.00	2.00	2.50	10.00		s_{25}	3.50	1.50	11.50	1.67	2.75	8.00
	s_4	2.00	2.00	12.00	2.00	3.00	4.50		s_{26}	1.50	3.50	3.00	0.00	0.00	0.00
	s_5	2.00	2.00	8.50	2.00	3.00	10.25		s_{27}	2.00	3.50	11.00	0.00	3.00	9.50
	s_6	2.00	1.00	7.50	2.00	2.00	9.50		s_{28}	1.50	3.00	1.50	0.00	0.25	1.00
	s_7	3.50	1.00	11.00	3.00	2.50	4.50		s_{29}	2.00	4.50	10.50	3.00	2.50	4.75
	s_8	1.50	1.00	6.50	0.00	2.00	1.00		s_{30}	3.50	2.00	15.00	3.00	3.50	9.75
	s_9	2.50	0.50	5.50	1.00	3.00	2.00		s_{31}	2.50	5.50	10.50	0.00	1.75	3.50
	s_{10}	2.50	0.00	0.50	1.00	1.50	2.50		s_{32}	1.50	2.00	2.50	2.00	1.50	7.50

	$\bar{x}$	2.25	1.90	9.20	1.70	3.60	6.50
	$s_{\bar{x}}$	.30	.53	1.17	.35	.32	1.18
		b_1			b_2		
		Y_1	Y_2	Y_3	Y_1	Y_2	Y_3
a_1c_2	s_{11}	3.25	5.50	12.25	1.00	3.50	7.00
	s_{12}	0.00	5.00	8.00	1.00	1.00	6.50
	s_{13}	3.50	4.50	10.50	2.00	1.50	3.50
	s_{14}	3.50	5.00	14.00	4.00	3.00	14.00
	s_{15}	4.00	1.00	6.50	2.00	2.75	7.00
	s_{16}	3.00	1.00	15.50	2.00	2.50	11.00
	s_{17}	3.00	3.00	6.00	3.00	3.00	11.50
	s_{18}	3.00	3.50	11.00	3.00	2.00	7.00
	s_{19}	4.00	2.00	8.50	2.00	1.50	6.00
	s_{20}	4.00	4.50	13.50	4.00	3.50	17.00
	s_{21}	3.50	.00	9.50	1.00	1.50	7.50
	s_{22}	3.50	1.00	11.50	1.00	1.00	6.00

	s_{33}	3.50	0.75	11.00	2.00	3.00	9.50
	s_{34}	3.00	2.00	6.50	2.00	3.00	6.00
	$\bar{x}$	2.50	2.98	8.58	1.56	2.19	6.29
	$s_{\bar{x}}$	.27	.48	1.07	.32	.29	1.08
		b_1			b_2		
		Y_1	Y_2	Y_3	Y_1	Y_2	Y_3
a_2c_2	s_{35}	2.50	2.00	6.50	1.00	2.50	2.00
	s_{36}	3.50	2.00	11.00	1.50	2.75	5.50
	s_{37}	3.00	1.00	8.50	2.00	1.00	5.00
	s_{38}	0.50	0.00	9.50	0.00	0.50	3.00
	s_{39}	2.50	2.00	8.50	2.00	2.00	6.00
	s_{40}	3.00	4.00	14.50	3.00	2.25	6.50
	s_{41}	2.00	1.00	6.50	0.00	0.50	1.00
	s_{42}	3.50	1.00	12.00	2.00	3.50	8.50
	s_{43}	3.00	4.50	7.50	2.00	1.75	7.00
	s_{44}	4.00	2.00	14.00	0.00	1.75	12.00
	s_{45}	4.00	1.00	10.50	3.00	3.50	6.50

$\bar{x}$	3.19	3.00	10.56	2.17	2.23	8.67
$s_{\bar{x}}$	.27	.48	1.07	.32	.29	1.08

$\bar{x}$	2.86	1.86	9.91	1.50	1.81	5.73
$s_{\bar{x}}$	.28	.50	1.11	0.33	.30	1.13

A = Instructional methods
a_1 = The experiment method
a_2 = Computer simulation

B = Trial
b_1 = Burning of metals
b_1 = Reactions of metals

C = Class
c_1 = class 8c
c_2 = class 8d

A = Dependent variables
Y_1 = Prior knowledge
Y_2 = Observation knowledge
Y_3 = Application knowledge