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SIMULATIONS IN SCIENCE EDUCATION – STATUS QUO

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ABSTRACT
During the last decades digitalization has proceeded rapidly and various digital teaching and learning tools are available nowadays. One for science education typical and theoretically well described application are simulations. While previous research focused on design features and/or learning effects of the use of simulations, up to now little is known about the extent to which simulations are actually used in science classes. In this study the use of simulations in science education is analyzed as well as (design) features which are important for teachers when choosing a simulation. 76 teachers were surveyed through a (online) questionnaire. 61% of the asked teachers use simulations in their lessons, independent of their age, teaching experience and number of science lessons per week. Significant differences occurred depending on the sex of the teachers, school type and subject. When choosing simulations, teachers use a limited number of known online providers. The most important (design) features are *scientific correctness*, *use of scientific language*, *free availability*, *clear visual design* which is *similar to everyday-life*, and matching *technical resources*. Of minor importance are features which consider the diversity of the learning group.

Background: Over the past decades the supply of digital media has grown steadily and partially very specific offers, such as simulations, have been developed for science education. The use of digital media is intended to increase the teaching quality and to enhance student's digital literacy (KMK, 2016). Various studies have shown that the use of simulations can, among other things, help to increase students' interest and motivation, improve their conceptual understanding, and generate stronger and longer-lasting learning effects (de Jong & von Joolingen, 1998; Baumann, Simon, Wonisch, & Guttenberger, 2013; Rutten, von Joolingen, & van der Veen, 2012; Vogel et al., 2006).

Purpose: The purpose of the current study is to determine, whether the potentials of simulations are recognised and used by science teachers. This leads to the following questions: (i) To what extent do science teachers use simulations in science education? And, if we assume that simulations are used at least to some extent: (ii) Which (design) features are of significance for science teachers when choosing a simulation?

Sample/Setting: The sample contains 76 teachers (36 male and 40 female) from the natural sciences who were addressed by e-mail. The participants are on average 42.5 (SD = 9.3) years old and have been teaching for 12.2 (SD = 8.0) years at lower (grades 5 to 10) and/or senior level (grades 11 to 13) high schools in Northern Germany. The participating teachers have medium to good technical resources. 61% of the participants (n = 46) use simulations in science classes, 39% (n = 30) do not, which leads to slightly different sub-sample sizes.

Design Methods: The use of simulations in science teaching is investigated with the help of a self-designed (online) questionnaire. All tasks were reviewed by experts (n=7) and tested in a pilot study (n=11). Possibly misleading formulations were revised to ensure objectivity. Validity was ensured by combining open and closed tasks. Furthermore, reliability can be assumed since no multi-item scales were calculated. Additionally, inter-item correlation was analyzed in order to ensure internal consistency.

Results: 61% of the teachers surveyed use simulations in their lessons. The use of simulations does not depend on age ($M = 42.51,\ SD = 9.31,\ p = .735$) or years of experience ($M = 12.24,\ SD = 8.03,\ p = .578$) of the teachers, nor on the number of subject lessons per week ($p_{Bio} = .291$; $p_{Che} = .329$; $p_{Phy} = .068$; $p_{Sci} = .699$). There are significant differences in the use in terms of sex ($\chi^2\ (1, N = 76) = 3.916, p = .048^*$), school type ($\chi^2\ (6, N = 76) = 15.759, p = .015^*$) and subject ($\chi^2\ (4, N = 103) = 11.928, p = .018^*$). Especially physics teachers at high school level (*Gymnasium*) use simulations. Only a limited number of providers is used, whereby the level of awareness and use is significantly related to the subject ($.000^* < p < .037^*$) (Stinken-Rösner & Abels, 2020a). Most important reasons for the use of simulations are the illustration of non-visible processes, the compensation of missing, defective or dangerous experimental materials as well as the lower effort and more reliable results compared to real experiments. Ranked on a 4-point Likert scale, the most important criteria when choosing a simulation are *scientific correctness* (M = 3.9, SD = 0.4), the *free availability* (M = 3.6, SD = 0.6), the *use of appropriate scientific language* (M = 3.5, SD = 0.6), *consideration of student's beliefs* (M =

3.4, SD = 0.7) as well as *qualitative presentation of relations* (M = 3.4, SD = 0.6). Of low importance, however, are features which consider the diversity of the learning group. Teachers who do not use simulations have (significantly) higher demands on simulations $(.000^{*} < p < .021^{*})$ than their experienced colleagues.

Conclusions/Implications for classroom practice and future research: Even though simulations seem to be already an integral part of today's science education which enhance students' experimental experiences, teachers need to be better equipped with findable and accessible high-quality simulations, which fit their teaching demands. Additionally, special professional development courses need to be designed to ensure that (ongoing) teachers can develop the competencies to identify simulations, integrate them into their teaching and reflect on their use. Simulations can be a resource to enable participation for all students, but may open other barriers at the same time (Stinken-Rösner & Abels, 2020b). Hence, further research about the effective implementation, especially in inclusive science education, is necessary.

Keywords: *Science Education, Experiments, Digital Media, Simulations*

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1 INTRODUCTION

The digitalization has proceeded rapidly during the last decades. Concurrently the supply of digital media for educational purposes has grown steadily. From the view of education, the use of digital media has two purposes: to increase the quality of teaching and learning and to enhance student's digital literacy (conference of German ministers of education (KMK), 2016).

Especially teaching tools, designed for science education, are very specific. In the context of science education, simulations are a typical application of digital media used for teaching and learning. Simulations are computer applications which "[…] give students the opportunity to observe a real-world experience and interact with it" (Sahin, 2006, p. 132).

Simulations have been developed to give students access to phenomena or lab experiences, which are not or only limitedly realizable in science rooms. This includes the fostering of procedural skills like the operation of scientific equipment (e.g. microscope, Bunsen burner or multimeter) and typical lab procedures as well as the use of simulations as supplement to real-world experiments, which are not realizable in science rooms.

Nowadays, various simulations are online available (overview in Stinken-Rösner & Abels, 2020a), the majority of them focussing on experiments. However, previous research mainly focused on the comparison of simulations with other media (Plass & Schwartz, 2014) or design features of simulations. So, the question arises whether simulations already became an integral part of today's science education (which is solely not documented) or which reasons hinder teachers from implementing simulations into their teaching.

2 RESEARCH BACKGROUND

"The experiment plays a key role in teaching science. Science instruction without any experiment is hardly conceivable" (Duit & Tesch, 2010, p. 17). Accordingly, up to two thirds of lesson time is governed in experimental situations, depending on the teacher and topic (Tesch & Duit, 2004). There are various variants of real-world experiments which can be found in science classes – ranging from teacher-centred demonstrations to open-ended student inquiries. Additionally, a growing number of digital tools was designed to give students access to experimental situations, which are not possible in science classes for whatever reasons.

One tool, which is of particular importance in the context of experiments, are simulations. Simulations are a powerful supplement to real-world experiments. A series of prominent reasons for the use of simulations in educational activities can be found in relevant literature, for example, ease of use, cost effectiveness, easy availability, saving of time, potential to compensate dangerous experimental materials, possibility of timescale manipulations, use of simplified models, simple manipulation of variables, presentations of phenomena which cannot be realized in the classroom, increased time for teacher-student interaction, use of varying representations, allowing for more lab experiences and active exploration, problem-solving experiences, provision of open-ended inquiry experiences, participation of all students, enhancement of student engagement, activation of previous knowledge and provision of immediate feedback (Blake & Scanlon, 2007; de Jong, 1991; de Jong & Njoo, 1992; Gupta, 2019; Podolefsky, Perkins, & Adams, 2010; Sadler, Whitney, Shore, & Deutsch, 1999; Sapp, 2018; Stinken-Rösner & Abels, 2020b).

Furthermore, studies have shown that the use of simulations can, among other things, increase the interest and motivation of students, improve their scientific, procedural and conceptual understanding, and generate stronger and longer lasting learning effects (Baumann, Simon, Wonisch, & Guttenberger, 2013; de Jong & von Joolingen, 1998; Gupta, 2019; Hensberry, Moore, & Perkins, 2015; Keller, Finkelstein, Perkins, & Pollock, 2007; Rutten, von Joolingen, & van der Veen, 2012; Vogel et al., 2006).

However, previous research mainly focused on the comparison of simulations with other media (Plass & Schwartz, 2014) or the usability of simulations in terms of design features. Figure 1 summarizes by various studies identified design features which improve usability and enhance student engagement.

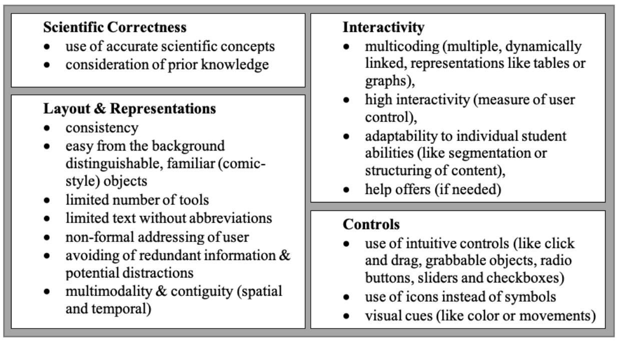

Fig. 1. Design features of simulations (Adams, Perkins, & Wieman, 2006; Adams et al., 2008a; 2008b; Blake & Scanlon, 2007; Girwidz, 2004; Homer & Plass, 2014; Jones, Jordan, & Stillings, 2005; Landriscina, 2013; Lee, Plass, & Homer, 2006; Mayer, 2001; 2009; Plass, Homer, & Hayward, 2009; Plass, Letourneau, Milne, Homer, & Schwartz, 2013; Yang, Andre, Greenbowe, & Tibell, 2003).

It is obvious, that a strong theoretical background concerning the design and use of simulations in science education already exists, but only little is known about the extent to which simulations are actually used in science classes. Tesch and Duit (2004) report that in almost 200 analyzed physics lessons no simulations were used at all. Various other authors, such as Gupta (2019, p. 2), state, that „in chemistry instruction, computer simulations are replacing traditional demonstrations, and laboratory work […]", but without providing explicit numbers or evidence.

This leads to the following questions:

(i) To what extent do science teachers use simulations in science education?

So far, we do not have an overview about the use of simulations in science classrooms. Regarding the increasing development of simulations for science education, we can assume that simulations are (at least to some extend) used in science classes.

(ii) Which (design) features are of significance for science teachers when choosing a simulation?

If we assume that teachers use simulations, the question arises, which resources they prefer for which reasons. The identification of appropriate (digital) resources for a specific learning objective, context, pedagogical approach, learner group, and teaching style belongs to the key competencies of educators (Redecker, 2017). Therefore, simulations should not only be examined in terms of usability but also in terms of teachers' requirements.

3 METHODS AND DATA

In order to examine the use of simulations in science education a self-designed questionnaire was developed. The survey was available online and as paper version. It consists of four sections: 'Use of experiments and simulations', 'Choice of simulations', 'Demographic data' and 'Technical resources'. Teachers who do not use simulations receive a slightly modified version (Tab. 1), which leads to two sub-samples: teachers using simulations (sub-sample: SIM) and teachers not using simulations (sub-sample: No SIM).

The questionnaire was examined by experts (n = 7) and piloted with pre-service teachers (n = 11). Possibly misleading formulations were revised to ensure objectivity. Validity was ensured by combining open and closed tasks (derived from literature, see section 2) so that no possible answers are excluded beforehand. Furthermore, reliability can be assumed, since all measured variables are independent and accordingly no multi-item scales were calculated (Wanous & Hudy, 2001). Additionally, inter-item correlation was analyzed in order to ensure internal consistency. An overview of the final items and corresponding answer formats can be found in Tab 1.

Tab. 1. Overview of the used items. The second column contains the answer format, the third the (sub-)sample, which was asked.

Item	**Answer format**	**Sample**
Section 1: Use of experiments and simulations		
Given lessons per week	Open ended	All
Quantitative use of real-world experiments	Single choice	All
Quantitative use of simulations	Single choice	SIM
Reasons for/against the use of simulations	Open ended	SIM/No SIM
Teaching phases in which simulations could be/are used	Multiple choice	All
Social forms in which simulations could be/are used	Multiple choice	All
Section 2: Choice of Simulations		
Known providers of simulations	Multiple choice & open ended	All
Approach when choosing simulations	Open ended	No SIM
Preferred simulation style	Single choice	SIM
Features of "good" simulations	Open ended & Likert-Scale	All
Section 3: Demographic data		
School type	Single choice	All
Teaching experience (years)	Open ended	All
Gender	Single choice	All
Age	Open ended	All
Section 4: Technical resources		
Availability of internet, WLAN, beamer, interactive Whiteboard, Computer, Tablets and Smartphones for teacher and students	Multiple choice	All

3.1 Sample

Schools in Northern Germany were addressed by e-mail with the invitation to participate in the current study. In total, 76 teachers (36 male and 40 female) from the natural sciences (25 biology, 27 chemistry, 37 physics, and 14 natural sciences (combination of biology, chemistry and physics in one interdisciplinary subject, only at lower secondary school)) participated. The participants are on average 42.5 (SD = 9.3) years old and have been teaching for an average of 12.2 (SD = 8.0) years at schools in Northern Germany. Participants teach at lower (*Sekundarstufe I (grades 5-10)*, n = 20) and/or senior level (*Sekundarstufe II (grades 11-13)*, n = 39 / n = 2) high school, as well as at other schools (n = 15). Significant differences occur in the gender distribution of teachers among subjects (χ^2 $(4, N = 76) = 19.639, p = .001^*$) and school levels ($\chi^2$ $(4, N = 76) = 14.039, p =$

$.007^*$). The share of female participants is greater in biology, balanced in chemistry and science and lower in physics. Female participants work more often at lower level schools.

On average, the participants give 6.5 (SD = 3.1) biology, 6.5 (SD = 3.6) chemistry, 7.7 (SD = 5.1) physics and 6.8 (SD = 7.1) science lessons per week. The asked teachers are provided with medium to good technical resources (60 % tablets, 70 % smartphones, 80 % computers, 60 % internet, 90 % projectors) in science rooms (Fig. 2). These include stationary equipment as well as mobile devices and 'bring your own device' (BYOD).

Fig. 2. Technical resources (stationary, mobile and BYOD) in science rooms.

61 % of the participants (sub-sample: SIM, n = 46) use simulations in science classes, 39 % (sub-sample: No SIM, n = 30) do not, which leads to slightly different sub-sample sizes.

4 RESULTS

The results are presented in two parts: First, the current use of simulations in science education and second, the reasoned choice of simulations and features of simulations which teachers consider as important. Both parts are analyzed with respect to demographic data of the participants and are presented, if necessary, separately for the two sub-samples.

4.1 The Use of simulations

To assess the current use of simulations, the use of real-world experiments in science classes is used as comparison. On average, one experiment is carried out in every tenth biology lesson, in every third science lesson and in every second chemistry and physics lesson. There are no significant differences in the quantitative use of real-world experiments between the sub-samples ($M_{Bio} = 0.11$, $SD_{Bio} = 0.08$, $p_{Bio} = .344$; $M_{Che} = 0.47$, $SD_{Che} = 0.33$, $p_{Che} = .495$; $M_{Phy} = 0.47$, $SD_{Phy} = 0.43$, $p_{Phy} = .497$; $M_{Sci} = 0.32$, $SD_{Sci} = 0.48$, $p_{Sci} = 1$).

Additionally, teachers of the sub-sample SIM use simulations on average in one of four/seven/ten lessons (science/physics/biology & chemistry) ($M_{Bio} = 0.08$, $SD_{Bio} = 0.06$; $M_{Che} = 0.11$, $SD_{Che} = 0.11$; $M_{Phy} = 0.15$, $SD_{Phy} = 0.15$; $M_{Sci} = 0.27$, $SD_{Sci} = 0.34$). This results in a total number of one experimental situation (sum of performed experiments and used simulations) every seventh biology lesson and in more than every second chemistry, physics and science lesson. The total number of experimental situations is comparable for both sub-samples in chemistry, more experimental situations are provided in biology ($M_{Bio} = 0.15$, $SD_{Bio} = 0.12$, $p_{Bio} = .011^*$), physics and science lessons (sub-sample SIM) due to the use of simulations ($M_{Che} = 0.54$, $SD_{Che} = 0.35$, $p_{Che} = .900$; $M_{Phy} = 0.60$, $SD_{Phy} = 0.51$, $p_{Phy} = .154$; $M_{Sci} = 0.40$, $SD_{Sci} = 0.54$, $p_{Sci} = .298$).

These results let suggest that simulations are used additionally, not as replacement for real-world experiments in biology, physics and science, whereas chemistry teachers who use simulations perform slightly fewer real-world experiments.

The use of simulations does not depend on age ($M = 42.51$, $SD = 9.31$, $p = .735$) or years of experience ($M = 12.24$, $SD = 8.03$, $p = .578$) of the teachers, nor on the number of subject lessons per week ($p_{Bio} = .291$; $p_{Che} = .329$; $p_{Phy} = .068$; $p_{Sci} = .699$). Significant differences exist, however, with respect to the sex of the teachers ($\chi^2\,(1, N = 76) = 3.916, p = .048^*$), the school type ($\chi^2\,(6, N = 76) = 15.759, p = .015^*$), the subject ($\chi^2\,(4, N = 103) = 11.928, p = .018^*$), and the internet connection ($\chi^2\,(2, N = 76) = 6.939, p = .031^*$). Especially physics teachers at high school level (*Gymnasium*) use simulations.

Simulations are used (sub-sample: SIM) to introduce a new topic (29 %) and for the acquisition (82 %), repetition (56 %) and deepening (89 %) of scientific content. 22 % of the participants use simulations for examinations, 20 % for homework. 76 % of the asked teachers use simulations in teacher-centred situations, 39 % for partner or group work and 9 % for individual work.

Lesson phases, in which simulations are used, are independent of the taught subject ($\chi^2\,(24, N = 46) = 35.536, p = .061$), whereas social forms depend significantly on the subject: simulations are mainly used in teacher-centred situations in biology, chemistry and physics and for partner/group work in science classes ($\chi^2\,(12, N = 46) = 22.160, p = .036^*$).

Main reasons for (sub-sample: SIM) or against (sub-sample: No SIM) the use of simulations are summarized in Tab. 2.

Tab. 2. Reasons for and against the use of simulations in science classes. The percentages refer to the respective sub-sample.

Reasons for the use of simulations (sub-sample: SIM, n = 46)	**Reasons against the use of simulations (sub-sample: No SIM, n = 30)**
Visualization of non-visible processes (26 %)	Missing or poor technical resources (37 %)
Compensation for missing, defective or dangerous experimental material (19 %)	No "good" simulations are known (23 %)
Less effort compared to experiment (10 %)	Lack of own experience (17 %)
More reliable results compared to experiment (5 %)	Higher effort compared to experiment (10 %)

When deciding between the use of real-world experiments or simulations, pragmatic reasons often play a crucial role. The participants favour simulations instead of real-world experiments, if it is not possible to perform the real-word experiment due to missing, defective or hazardous materials, if the real-word experiment is very tedious or complex or if the results of the real-world experiment are not reliable.

4.2 Resources and design features of simulations

Most famous providers of simulations for science teaching and learning are the internet portals *Planet Schule*, *LEIFI Physik* and *PhET* (Stinken-Rösner & Abels, 2020a). The online platform *Planet Schule* is operated by the German TV broadcaster SWR/WDR. It contains learning materials for all grades, mainly educational TV clips with additional background information and learning materials. The platform contains around 70 simulations, covering all science disciplines, which can be used online. *LEIFI Physik*, operated by the Joachim Herz Stiftung, focusses on physics learning materials for grades 5-13, such as experiments (simulations), tasks, quizzes and background information. Around 150 different simulations from various providers (own developments, *cK-12*, *Walter Fendt*, *PhET*, etc.) are gathered and available for online use. The *PhET* project, initiated by the University of Colorado Boulder, develops simulations for science (biology, chemistry, physics, geography) and mathematics teaching and learning. Over 150 simulations are online or as download available and approximately 80 as well via the *PhET* APP. The online portal provides additional materials to each simulation as well as a platform for teacher to share their materials. Over all, the majority of available simulations covers physical content, followed by chemical and biological (Stinken-Rösner & Abels, 2020a).Within the sub-sample SIM biology and chemistry teachers mainly use the platform *Planet Schule*, physics teachers *LEIFI Physik* and science teachers *PhET* (Stinken-Rösner & Abels, 2020a), whereby use and subject are significantly related ($\chi^2{}_{planet\ Schule}\ (8, N = 46) = 16.428, p_{planet\ Schule} = .037^*$; $\chi^2{}_{LEIFI}\ (8, N = 46) = 53.772, p_{LEIFI} = .000^*$; $\chi^2{}_{PhET}\ (8, N = 46) = 25.914, p_{PhET} = .001^*$) (Stinken-Rösner & Abels, 2020a). The use of the most famous providers is therefore related to the respective subject-specific content.

Participants of the sub-sample No SIM stated, that they would use online search engines (55 %) or additional materials provided by educational publishing houses (16 %), e.g. DVDs, when researching simulations for the first time. Overall, simulations which are provided online and easy to find seem to play a crucial role.

Figure 3 shows exemplarily four different simulations of the leverage effect. The majority of participants (sub-sample: SIM) prefer the simulation shown in sub-figure 3a) (49 %), followed by sub-figure 3b) (27 %), 3c) (15 %) and 3d) (<10 %). These results are independent of the taught subject ($\chi^2\ (12, N = 46) = 12.240, p = .427$) and of the known providers ($\chi^2\ (3, N = 46) = .750, p = .861$). Teachers do not prefer, as could be easily assumed, providers which they are familiar with. It seems like not the popularity of a provider matters, but the features of the individual simulation. This assumption is also supported by the fact that even if participants of the sub-sample No SIM are familiar with common providers, they state nonetheless that they are not familiar with "good" simulations (Tab. 2). Therefore, a more detailed analysis of features like visual design, content and interactivity seems necessary.

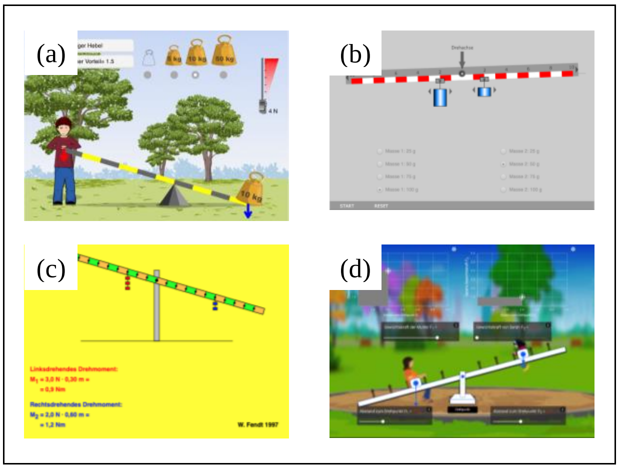

Fig. 3. Different simulations of the leverage effect from various providers. (a) eduMedia (n.d.), (b) mackSPACE (Mack, n.d.), (c) Walter-Fendt (Fendt, 1997) and (d) cK12 (n.d.). The majority of participants (sub-sample: SIM) favoured simulation (a).

In order to analyze individual features, which are important for teachers when choosing simulations, participants stated up to five features of a "good" simulation in order of significance and, additionally, rated various theory derived design features on a four-point Likert scale.

When asked to state features of "good" simulations, the most frequently given answers (weighted by number of naming and assigned significance) are *clarity/intuitive operation*, *fit to technical resources*, *scientific correctness*, *didactical reduction of content*, *visual design* and *visual similarity to everyday-life*. The ratings of the participants concerning the given, theory-based features are shown in Fig. 4.

For teachers the most important features when choosing a simulation, judged on a 4-point Likert scale, are the *scientific correctness* (M = 3.9, SD = 0.4), the *free availability* (M = 3.6, SD = 0.6), the *use of appropriate scientific language* (M = 3.5, SD = 0.6), *consideration of student's beliefs* (M = 3.4, SD = 0.7) as well as *qualitative presentation of relations* (M = 3.4, SD = 0.6).

Of minor importance, however, is the *consideration of cultural diversity* (M = 2.1, SD = 1.0), a *gender-sensitive language* (M = 2.0, SD = 0.9) or *multilingualism* (M = 2.0, SD = 0.8).

Generally, teachers from the sub-sample No SIM have significantly higher demands on simulations than their experienced colleagues (Fig. 4, marked by asterisks) ($.000^* < p_i < .036^*$). Also, significant differences occur for eleven features regarding the school type: *consideration of diversity* ($M = 2.3,\ SD = 1.1,\ p = .001^*$), *German language* ($M = 3.2,\ SD = 0.9,\ p = .000^*$), *visual similarity of everyday-life* ($M = 2.9,\ SD = 0.7,\ p = .000^*$), *interesting context* ($M = 3.0,\ SD = 0.9,\ p = .001^*$), *different representations* ($M = 3.2,\ SD = 0.7,\ p = .006^*$), *qualitative presentation of relations* ($M = 3.4,\ SD = 0.6,\ p = .008^*$), *consideration of cultural diversity* ($M = 2.1,\ SD = 1.0,\ p = .015^*$), *opportunities for differentiation* ($M = 3.1,\ SD = 0.7,\ p = .020^*$), *visual similarity to laboratory* ($M = 2.5,\ SD = 0.7,\ p = .024^*$) and *automated feedback* ($M = 2.2,\ SD = 0.9,\ p = .048^*$). In particular, features relevant to a diverse learning group are of greater importance to teachers working in lower education.

Returning to the simulations of the leverage effect shown in Fig. 3, it becomes clearer why teachers prefer simulation a). Simulations a) and d) have a modern design and are visually similar to everyday-life ($\chi^2{}_{modern\ design}\ (9, N = 46) = 21.528, p = .010^*$). Additionally, relations are only shown qualitatively in simulation a) ($\chi^2{}_{qual.\ presentation}\ (6, N = 46) = 17.555, p = .007^*$), therefore it has a greater clarity than simulation d).

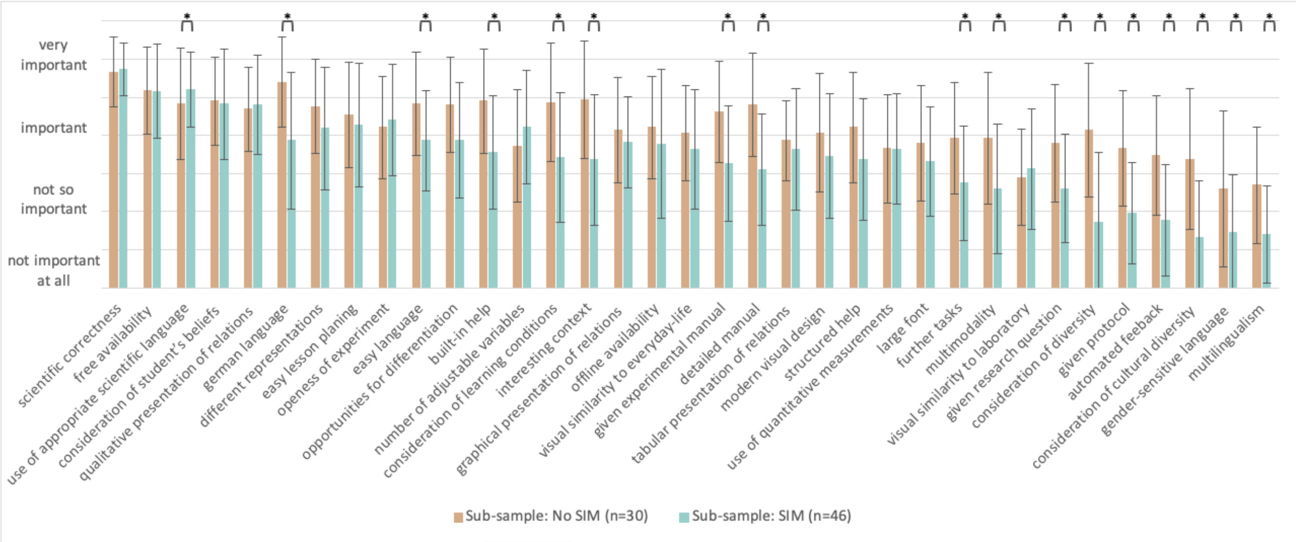

Fig. 4. Participants rating of various simulation features on a four-point Likert scale. Indicated errors represent standard deviation. The beige bars represent the sub-sample No SIM and the green bars the sub-sample SIM. Significant differences are marked with asterisks.

5 DISCUSSION AND CONCLUSIONS

61 % of the teachers surveyed already implemented simulations in science teaching and learning. The use of simulations does not depend on age or experience of the teachers, nor on the number of subject lessons per week. Significant differences exist, however, with respect to the sex of the teachers, the school type and the subject. Especially physics teachers at senior high school level use simulations. Reasons might be the significantly advanced technical resources, the taught content and/or a special affinity of physics teachers for technology and digital media. All participants working at the *Gymnasium* have access to the internet ($\chi^2\ (6, N = 76) = 13.662, p = .034^*$) and a projector ($\chi^2\ (6, N = 76) = 22.180, p = .001^*$) in science classes. Additionally, the number of in class realizable experiments decreases with grade, due to complexity and costs of the experimental setup.

Interestingly, differences in the use of simulations with respect to the sex of the teachers cannot be traced back to the different gender distribution among subjects and school levels. Other factors, like teachers' beliefs or attitudes (which were not captured in this study), might differ depending on the sex of the teachers and cause the observed differences.

On average, one simulation is used every four to ten lessons, depending on the subject. Teachers who use simulations provide as much or even more experimental experiences in their science classes than colleagues who use entirely real-world experiments. Simulations are used in all subjects for the acquisition, repetition and deepening of scientific content and/or procedural skills, whereas social forms in which simulations are used are predominated by teacher-centred situations.

Main reasons for the use of simulations are the visualization of non-visible processes, the compensation of missing, defective or dangerous material and more reliable results than real-world experiments. Reasons against the use of simulations are the lack of technical resources, no known "good" simulations and teacher experience.

When choosing a simulation, teachers rely on online search engines and online portals. The most important (design) features are *scientific correctness*, *didactical reduction of content*, *use of scientific language*, *clear visual design* which is *similar to everyday-life*, *free availability* and matching *technical resources*. Features which consider the diversity of the students (e.g., in culture, language, gender) are generally of less importance, whereby these features are significantly more important to teachers working in lower secondary education. Teachers who do not use simulations have in general significantly higher demands on them than their experienced colleagues.

From the presented results, several implications for developers, classroom practice and future research can be derived. First, already existing simulations should be reviewed and new simulations developed with regard to usability and demands of science teachers. So far, the majority of available simulations cover physical topics, a comparable offer in biology and chemistry is still missing. In the end teachers decide about the appropriateness and the actual use of (digital) resources. If simulations do not fit their needs, they will not use them. Second, simulations need to be easily findable and accessible for teachers, e.g., in online platforms sorted by class and topic. This also includes internet access in all science classrooms, since most simulations are only available online. Third, teachers need special courses and a safe space to test pre-selected high-quality simulations. Teachers need to develop the competencies to identify simulations, integrate them in their teaching and reflect on their use for their lessons. Best practice examples need to be identified and analyzed. In this context, physics education could be a role model for the other subjects due to its pioneering role in the use of simulations. However, subject specifics need to be reflected and compared to better understand this role. Also, reasons for the gender specific differences in the use of simulations need to be examined in more detail. Another research desiderate is the application of simulations in inclusive science education. Findings of the current study indicate that features which cater to the diversity of students are of greater importance in diverse or marginalised learning groups. The use of simulations can be a resource to enable participation for all students, but may open other barriers at the same time (Stinken-Rösner & Abels, 2020b). Basic digital skills like the handling of hardware and software and knowledge of common controls are necessary. Disadvantages for individual students can arise if the necessary technical resources are not available, e.g. for homework. Also, simulations often do not have the same authenticity as real experiments. The visual similarity to computer games can lead to unintentional playing instead of a planned inquiry. A general problem of almost all simulations in the field of chemistry is the graphical mixing of macroscopic and submicroscopic elements in favour of usability. For example, the simultaneous display of beakers at macroscopic and molecular particles at submicroscopic level, whereby macroscopic properties such as colour and shape are assigned to them.

The presented study provides a first overview about the use of simulations in science education from which implications for development, practice and research were derived. Nevertheless, some limitations need to be considered such as the number of participants and the chosen empirical approach.

Up to now, most studies focussed on the design and use of simulations from student perspective (see section 2). Teachers' beliefs and attitudes concerning simulations were analyzed occasionally (e.g. Zacharia, 2003), the actual usage of simulations in school was hardly considered. Accordingly, suitable test instruments had to be developed first. In the presented study a self-designed questionnaire was used. The questionnaire was examined and piloted to ensure objectivity, validity and reliability. However, the gathered data reflects teachers' perceptions, an objective analysis concerning the use of simulations in science education can only be done by lesson observations.

Another limitation is the number of participants. Additionally, the voluntary participation of the teachers might lead to a shift in the data. It can be assumed, that the motivation to participate in the presented study is higher if the asked teachers use simulations. Therefore, the share of teachers, which actually use simulations in science classes, could be smaller than indicated by the data.

Based on this, further data needs to be collected in order to get a better understanding of the usage and role of simulations in science education in Germany and worldwide. Currently, the use of simulations in science education at primary school (grades 1-4) is investigated in the context of a qualification thesis.

Simulations are already an integral part of today's science education which enhance students' experimental experiences. But still, teachers need to be better equipped with high-quality simulations and prepared to integrate simulations adequately in (diverse) teaching and learning processes. Hence, further research about the effective implementation, especially in inclusive science education, is necessary. Especially qualitative approaches like interviews and observation studies could lead to new insights about the choice and use of simulations in science education.

SUPPLEMENTARY MATERIALS

The questionnaires for both sub-samples (SIM and No SIM) can be derived from the journal site.

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