



How to Communicate Complex Research:

Effects of Hands-On Experiments and Computer Simulations in Marine Ecology Outreach Activities

DISSERTATION

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ZUSAMMENFASSUNG

Die Vermittlung von aktuellen wissenschaftlichen Themen mit gesellschaftlicher Relevanz an Jugendliche ist von großer Bedeutung, um sie angemessen auf das heutige sowie zukünftige Leben vorzubereiten und ihnen eine Grundlage für die nachhaltige Entwicklung der Gesellschaft zu bieten. Ein Beispiel für ein Thema, was besonders für Schülerinnen und Schüler rund um die Ostsee von Relevanz ist, sind die Veränderungen der Ostsee und die Auswirkungen auf das Ökosystem sowie die Gesellschaft. Der fachliche, didaktische und technische Anspruch einer fachlich qualitativen und mit Blick auf die Adressaten angemessenen Kommunikation solch komplexer Themen stellt große Herausforderungen für Wissenschaftler*innen oder Didaktiker*innen alleine dar.

Eine Umsetzungsmöglichkeit, die beide Perspektiven miteinander verbindet, ist ein Co-Design, wie es im Kiel Science Outreach Campus für die Entwicklung und Beforschung von Outreach-Aktivitäten insbesondere in außerschulischen Lernorten genutzt wird. Die hier vorliegende Dissertation stellt daher die interdisziplinäre Entwicklung und Evaluation zweier Outreach Aktivitäten für Oberstufenschülerinnen und -schüler im Schülerlabor der Kieler Forschungswerkstatt vor. Um einen authentischen Einblick in die Wissenschaft zu ermöglichen, erarbeiteten die Schülerinnen und Schüler die Auswirkungen zukünftiger Veränderungen der Ostsee in einem Zusammenspiel aus Hands-on Experimenten und einer interaktiven Computersimulation. Computersimulationen und Experimente sind wichtige Lernmethoden im modernen naturwissenschaftlichen Unterricht. Bisherige Studien konnten jedoch die pädagogisch-didaktischen Vor- und Nachteile beider Methoden nicht hinreichend klären und weisen oft keine ausreichende Vergleichbarkeit auf. Das übergeordnete Ziel dieser Arbeit war es daher, motivationale und kognitive Effekte von Hands-on Experimenten und interaktiven Computersimulationen zur Vermittlung komplexer Zusammenhänge zu untersuchen. Dafür wurde die Wirkung der Methoden auf Fachwissenszuwachs, situatives Interesse und Überzeugungen über die Wissenschaft zuerst in einem direkten Vergleich ($N_{\text{Studie I}} = 443$) und zweitens in einem kombinierten Ansatz ($N_{\text{Studie II}} = 367$) untersucht.

Die vergleichende Untersuchung (Studie I) ergab, dass eine Simulation mehr Wissen vermittelte und Experimente für ein höheres situatives Interesse sorgten. Der kombinierte Ansatz (Studie II) zeigte, dass zwei Methoden für die Vermittlung von Fachwissen besser sind als eine, da Experimente für Simulationen eine ergänzende Eignung zur Vermittlung von Grundlagenwissen besitzen. Durch das Zusammenspiel der beiden Methoden konnten die Vorstellungen über naturwissenschaftliche Vorhersagen positiv beeinflusst werden. Die Ergebnisse zeigten weiterhin, dass die Schülerinnen und Schüler ein grundsätzlich hohes Vertrauen in die Wissenschaft hatten.

An der Schnittstelle zwischen Science Communication und Science Education geben die Ergebnisse Hinweise für die erfolgreiche Umsetzung von Designs moderner Outreach Aktivitäten. Im Rahmen der Digitalisierung der Gesellschaft ergibt sich die Empfehlung, verstärkt interaktive Computersimulationen neben Hands-on Experimenten für die Vermittlung komplexer Inhalte einzusetzen. Kombinationen aus Experimenten und Simulation können dazu beitragen, ein umfassendes Verständnis und Interesse für komplexe aktuelle Sachverhalte der Naturwissenschaft zu ermöglichen und die Chancen beider Medien und Methoden miteinander zu verknüpfen.

ABSTRACT

The communication of current scientific topics with societal relevance to young people is of great importance in order to prepare them adequately for present and future life and to provide them with a solid basis for a sustainable development of society. An example of a topic that is particularly relevant to school students from the Baltic region is the changes in the Baltic Sea and their impacts on the ecosystem and society. The scientific, didactic and technical demands for communicating such complex topics in an authentic learning environment in a way that is appropriate to the subject matter and the target audience pose great challenges for scientists and educators all alone. One implementation option that combines both perspectives is a co-design, as used in the Kiel Science Outreach Campus for developing and investigating outreach activities, especially in out-of-school learning settings.

This doctoral thesis therefore presents the interdisciplinary development and evaluation of two outreach activities for secondary grade students in a student laboratory. The students worked out the effects of future changes in the Baltic Sea with hands-on experiments and an interactive computer simulation. Computer simulations and experiments are important learning methods in modern science education. However, existing research has not sufficiently identified the educational and didactical advantages and disadvantages of both methods and often lacks appropriate comparability. The overall goal of this doctoral thesis was therefore to investigate motivational and cognitive effects of hands-on experiments and interactive computer simulations for communicating complex research issues. The effects of the methods were investigated on knowledge gain, situational interest and beliefs about science first in a direct comparison ($N_{Study\ I} = 443$) and second in a combined approach ($N_{Study\ II} = 367$).

The comparative study showed that a simulation conveyed more content knowledge and experiments caused higher situational interest. The combined approach indicated that two methods conveyed more knowledge than one, and the combination of the two methods positively influenced the perceptions of scientific predictions. The results also showed that the students had a fundamentally high level of trust in science. At the interface between science communication and science education, the findings provide conclusive indications for the design of modern outreach activities. In the context of the digitalization of society, it is recommended to increasingly use interactive computer simulations in addition to hands-on experiments to convey complex content. Combinations of experiments and simulation can contribute to a comprehensive understanding of, and interest in complex current issues in science, and combine the potential of both media and methods.

*“Durch die Simulation sind die
Zusammenhänge deutlich geworden –
Die Experimente haben Spaß gemacht.”¹*

**„Experimente sind effizienter, da man davon
nicht so schnell und stark gelangweilt wird.“¹**

„Experimente legen mir das Thema näher,
Simulationen bringen es mir besser bei.“¹

„An sich finde ich Simulationen gut, aber bei
dieser Thematik hätten mir nur Experimente
mit Erklärungen mehr Spaß gemacht.“¹

***„Es hat mir gezeigt wie die Ostsee funktioniert
und ich habe bemerkt, es ist kompliziert.“¹***

¹ Student statements in the free comment field evaluating the methods used in the student lab day

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1 MOTIVATION & OBJECTIVES

The main objective of education is the development of appropriate knowledge and competencies to prepare young people adequately for life in the present and future society. This means enabling them to participate actively and responsibly in social, political, ecological and economic life in order to achieve sustainable development (Kultusministerkonferenz, 2005; UNESCO, 2016). There are many current scientific topics with societal relevance whose content and research should be communicated to students² in order to achieve this goal. These so-called socioscientific issues are often highly complex and cannot be adequately communicated by scientists or educators alone (Herman, Sadler, Zeidler, & Newton, 2018; Zeidler, 2014). This doctoral thesis intends to contribute to the understanding of how socioscientific issues can be successfully conveyed through science outreach activities. Science outreach describes a variety of activities between scientists and the public/laypersons aiming to increase public awareness and understanding of science and to contribute to science education (Poliakoff & Webb, 2007; Varner, 2014) (examples of science outreach activities include online discussions, science museums, student laboratories, science cafes, citizen science, etc.).

The consequences of anthropogenic influences on marine ecosystems are one of these socioscientific issues that already have far-reaching effects on all levels of society and probably will have even more severe effects in the future. Climate change, pollution, or habitat destruction are only a few of the threats that influence the functioning of marine ecosystems (Halpern et al., 2008; IPCC, 2019). These impacts are already affecting the survival, fitness, and interactions of numerous marine species, which in turn may alter the community structure and the provision of ecosystem services (Chapman, 2017; Doney et al., 2012; Poloczanska et al., 2013). In the shallow and land-locked Baltic Sea, for example, these changes seem to proceed at a particularly fast pace. Drivers such as warming, acidification, or eutrophication have already led to poorer water quality (for example due to deoxygenation) and a loss of biodiversity with negative socio-economic impacts (BACC, 2015; HELCOM, 2009). Some scientists argue that the Baltic Sea, as a severely anthropogenic disturbed ecosystem, can serve as a time machine for other sea areas that change slower (Reusch et al., 2018).

² The term "students" here and in the following means school children, not university students.

Recognizing that findings as these have global and paramount importance, the UN assigned a separate goal for sustainable development of marine ecosystems (SDG 14 “life under water”) (United Nations, 2015). Additionally, the European Commission declared the mission "Healthy Oceans, Seas, Coastal and Inland Waters" as part of the Horizon Europe framework program starting in 2021 (European Commission, 2021). The same year also marks the beginning of the United Nations Decade of Ocean Science for Sustainable Development (2021-2030) (United Nations, 2020b).

These landmark frameworks highlight the crucial importance of students' understanding of these complex changes and their impacts at local and global level, to contribute to the sustainable development of society. The fundamental goal of education described at the beginning requires the teaching and learning of “scientific literacy”. Scientific literacy competencies include the understanding of scientific concepts as well as evaluating, interpreting, and assessing scientific inquiry (National Research Council, 1996; OECD, 2017). For this purpose, students should gain an authentic insight into scientific processes and be able to understand the way of knowledge acquisition as required by international educational standards and national curricula (e.g. Kultusministerkonferenz [KMK], 2020). In the case of this doctoral thesis, special attention can be paid to teaching ocean literacy. Ocean literacy means understanding the ocean and our relationship with it. Dealing with regional changes and threats to the Baltic Sea thus offers a great potential, especially for North German students. The direct relation to everyday life can lead to a strong identification with the problem and to an increased awareness of its importance among the students. In the best case, the understanding of science is conveyed in an authentic way so that interest in science, a positive attitude toward science, and engagement in science activities can be promoted (Goldman et al., 1994; Labouta et al., 2018; Lee & Butler, 2003; Woods-McConney, Oliver, McConney, Maor, & Schibeci, 2013).

However, communicating complex findings of current research often poses high demands on scientists. They often lack knowledge as to how people learn about science and how it is possible to communicate such complex topics understandably (Treise & Weigold, 2002). Science educators provide these educational competencies, but often lack the understanding of complex research topics as well as insights into modern knowledge acquisition. With this in mind, the first objective of this doctoral thesis is:

Objective I

The interdisciplinary development of outreach activities for the authentic communication of the multifactorial anthropogenic influences on the Baltic Sea ecosystem.

The Baltic Sea represents one of the most intensively studied coastal areas, based on the available long-term data series as well as high quality and networked research (Reusch et al., 2018). Scientists often develop model-based simulations to collate and understand the large amount of data from measurements and experimental results (Graiff, Karsten, Radtke, Wahl, & Eggert, 2020; Meier et al., 2012; Neumann, 2010a). However, teaching of this combination of experiments and simulations as a modern scientific research method has so far been underrepresented in science education. Nevertheless, experiments and computer simulations alone are an established part of science education.

Experiment-based learning on the one hand plays a key role for understanding and teaching scientific concepts and working methods (National Research Council [NRC], 2012; National Science Teachers Association [NSTA], 2013; Pfeifer, Lutz, & Bader, 2011; Schulz, 2011). Hands-on experiments are especially useful for teaching basic processes and concepts (Köck, 2018; Mönter & Hof, 2012). However, they often represent replicas and simplifications of past processes of knowledge acquisition and often do not adequately reflect current research (Braund & Reiss, 2006). Hands-on experiments fall short when teaching complex issues, because they usually only teach one process at a time. Computer simulations, on the other hand, have become increasingly important in science education due to their modern and innovative opportunities for teaching (Blake & Scanlon, 2007; Rutten, van Joolingen, & van der Veen, J. T., 2012). They are an effective tool particularly in communicating complex processes and systems (Rieß, 2013; Rutten et al., 2012; Smetana & Bell, 2012). Interactive computer simulations promise to be highly attractive to students and increase their motivation and interest (Urhahne & Harms, 2006). Nevertheless, they often lead to a high cognitive load (Paas, Renkl, & Sweller, 2003) which negatively influences learning success (Jong, 2010; Jong & van Joolingen, 1998; Mayer, Hegarty, Mayer, & Campbell, 2005).

Direct comparisons of the advantages and disadvantages of these two learning methods have not yet shown any clear trend and often lack comparability (Edsall & Wentz, 2007; Stull & Hegarty, 2016; Winn et al., 2006). The different benefits of experiments and computer simulations suggest that a combination of both methods could be a potentially powerful learning tool (Lichti & Roth, 2018; Smetana & Bell, 2012). Current findings on learning with hands-on experiments and interactive computer simulations do not yet provide sufficient insights into cognitive and motivational processes of learning about current and complex issues. There is especially too little understanding of how forms of digital learning can interact with experimental learning for example in a combined approach. These considerations lead to the second objective of this thesis:

Objective II

The investigation of cognitive and motivational effects of experiments and simulations and different sequences of their combination in teaching current complex scientific topics.

The (combined) use of experiments and computer simulations has high potential not only on the educational level. Due to the digitalization of society, digital structures will be found in every area of work and life. Promoting students' digital competencies therefore is of great importance (Kultusministerkonferenz, 2017). Digital literacy represents a basis for successful participation in a society that is increasingly influenced by digital media, technology, and processes. As a result, an increasing number of digital learning environments are emerging in school and in out-of-school education. Recent developments in the times of COVID-19 pandemic further highlight the need for digital teaching. However, digital media per se do not guarantee high-quality education. This is shown, for instance, by the latest release of the meta-study by Hattie and Zierer (2018). While insufficient teaching does not improve with digital media, good teaching can benefit from the use of modern technology. Another large meta study on the effects of digital media in German schools also concludes that modern teaching should be digital, but that successful teaching is not exclusively digital (Hillmayr, Reinhold, Ziernwald, & Reiss, 2017). Consequently, how should modern science education activities be designed? The overall intention of this work is to contribute to the design and development of modern science outreach activities. Therefore, experiences from the development process are combined with empirical findings. This results in the third objective of this thesis:

Objective III

The derivation of criteria for the design of modern science outreach activities on the basis of the empirical studies and development process.

This doctoral thesis was conducted as part of the Leibniz ScienceCampus “KiSOC”. The Kiel Science Outreach Campus (KiSOC) was funded by the Leibniz association from 2016 to 2020 and aimed to investigate success factors for an understandable and motivating communication of the meaning and the results of science. For this purpose, various concepts and effects of different outreach activities were investigated. An essential aspect of a Leibniz ScienceCampus is the close cooperation between Leibniz institutions and universities (or other research institutions). This gives this doctoral thesis the special character of an interdisciplinary collaboration between marine ecological research and research in science education and media psychology. The interdisciplinary character is reflected in the design of the outreach activities as well as in the implementation of the empirical studies. The design of the activities combined expertise of marine biologists with the didactic knowledge of science educators. The empirical studies included didactical, media-psychological and science communication aspects. On the one hand, the conclusions are intended to show how complex topics can be communicated in science communication. On the other hand, they should contribute to the use of the learning methods hands-on experiments and interactive computer simulations in modern science education. The interface between science communication and science education provides the basis for the multiple goals of this work (Figure 1.1).

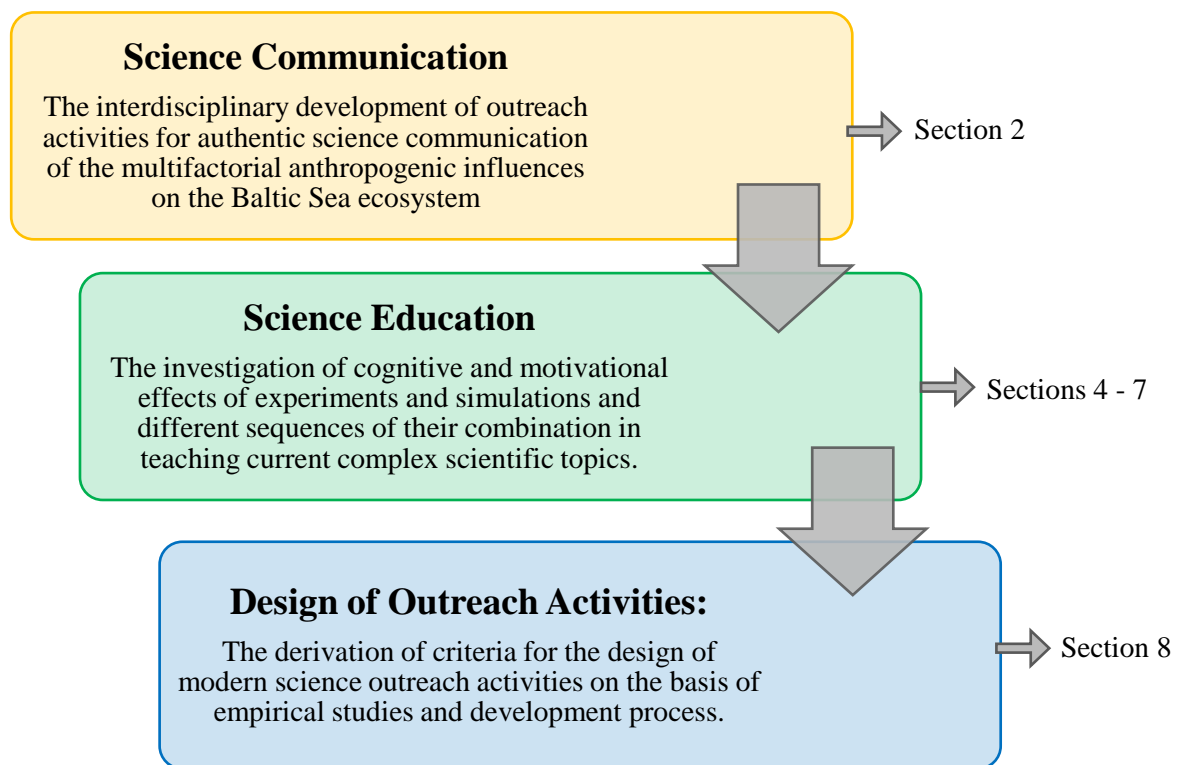


Figure 1.1. Overview of the objectives

In the following section, the co-design process of the marine ecology outreach activities in a student laboratory are described (Section 2). Subsequently, the research on motivational and cognitive effects of experiments and simulations are presented. The effects of the methods were investigated regarding knowledge achievement, situational interest, cognitive load, and students' beliefs in science in first a comparative and second a combined approach including the investigation of sequence effects. The results of these investigations are presented in the manuscripts (Section 4-6) as well as in the section of further results (Section 7). Finally, all results are summarized in a concluding discussion and indications for the design of future outreach activities are derived (Section 8).

2 CO-DESIGN PROCESS OF THE OUTREACH ACTIVITIES

The development of the outreach activities based on the Model of Educational Reconstruction (Duit, Gropengießer, Kattmann, Komorek, & Parchmann, 2012). For the design of the learning environments, firstly the scientific content was clarified and analyzed and secondly the students' perspectives were considered (Figure 2.1). These three equally important steps aim to adapt science knowledge to the students' perspective in a way that suitable teaching content can be developed (Komorek & Kattmann, 2008).

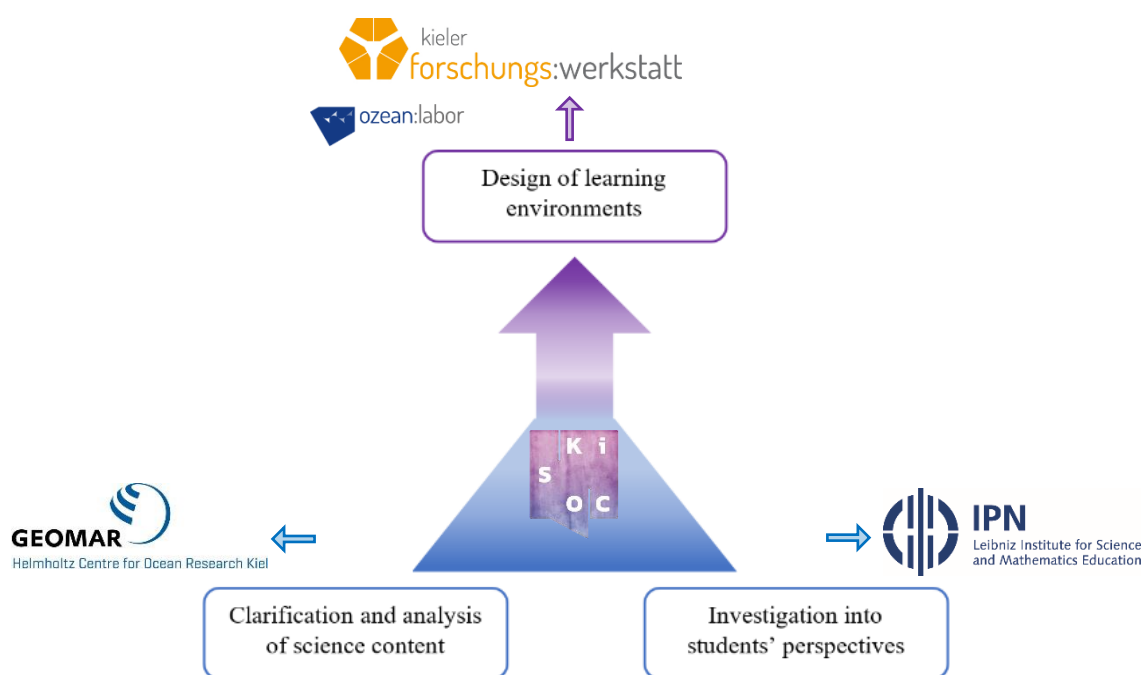


Figure 2.1. The Model of Educational Reconstruction (Duit, Gropengießer, Kattmann, Komorek, & Parchmann, 2012) expanded with the logos of the institutions associated with each step

Based on the KiSOC approach, the project was implemented in an interdisciplinary collaboration: The Benthic Ecology research group of the GEOMAR ensured the clarification and the analysis of the current scientific content. The department of chemistry education from the Leibniz Institute for Science Education and Mathematics (IPN) contributed to the didactic and the media-psychological perspectives of the project. As part of the program of the Kieler Forschungswerkstatt, the outreach activities were implemented. The resulting Professional Communities of Practice enabled the transfer of current, complex and interdisciplinary research content into outreach activities suitable for the target group. In the following, the different steps of this co-design process are described in more detail.

2.1 CLARIFICATION AND ANALYSIS OF SCIENCE CONTENT

The Baltic Sea is a young, semi-enclosed brackish water sea. The natural characteristics of this highly dynamic shelf sea include shallow water depth and low water exchange with the North Atlantic (Snoeijs-Leijonmalm, Schubert, & Radziejewska, 2017). The Baltic Sea is mainly affected by the consequences of climate change, by overfishing, and by human-induced nutrient as well as pollutant load (BACC, 2015). Simulations show that by the year 2100, warming of 2-4 °C and a reduction in the ice cover of 50-80 % will be possible (Andersson et al., 2015). An estimated increase in precipitation of up to 30% will lead to increased land runoff, resulting in increased input of organic matter as well as an overall reduction of salinity (Gräwe, Friedland, & Burchard, 2013). These multiple and synchronous human-induced pressures have led to rapid and pronounced changes in the Baltic Sea ecosystem (Reusch et al., 2018).

The effects of a singular (monofactorial) change on the organism level have been widely studied (direct impacts), for example, the negative influence of warming on the fitness of the macroalgae bladderwrack (*Fucus vesiculosus*) (Wahl et al., 2011). However, there often is a lack of certainty regarding the impact of the changes on the community level, which can be seen for example through shifts in biotic interactions (indirect impacts). Secondly, the effects of combinations of these changes on the structure and the function of entire communities also are not clear yet (Wahl et al., 2020). It is very important to understand these higher-order interactions to better predict future changes in marine ecosystems. Since society is highly dependent on the goods and services of marine ecosystems, there is a strong need to minimize the uncertainty of predictions as far as possible (Boyd et al., 2018). In current research, scientists upscale the experimental approaches in space, time, and complexity to remedy this lack of uncertainty (e.g. Riebesell & Gattuso, 2015; Wahl, Saderne, & Sawall, 2016). For this purpose, they investigate the effects of bi- or multifactorial simultaneous changes (e.g. warming and acidification) on whole communities (e.g. macroalgae, grazers, and epiphytes) taking into account their natural daily and seasonal fluctuations (e.g. Radatz, Guy-Haim, Rilov, & Wahl, 2017). An outstanding example of such an experimental facility is the Kiel Outdoor Benthocosms (KOB) operated by the research unit Benthic Ecology based at GEOMAR Helmholtz Centre for Ocean Research Kiel (Wahl, Buchholz et al., 2015).

The KOB facilities include six tanks on a floating platform at the Kiel Fjord with a seawater volume of 1500 liters each (Figure 2.2 and Figure 2.3). In the 12 subunits near-natural Baltic Sea shallow underwater scenarios can be simulated. For this purpose, aspiration pumps and wave generators enable water movements typical for coastal areas. A constant flow-through of seawater in the Benthocosms represents natural fluctuations of seawater parameters. Depending on the experimental design, the seawater parameters (temperature, pH-value, salinity, nutrients) of the subunits can be adjusted independently. Representative samples of the benthic community (macroalgae, grazers,

and epiphytes) can be kept together in the experimental tanks. For a precise description of the Benthocosms see Wahl, Buchholz et al. (2015).



Figure 2.2. The Kiel Outdoor Benthocosms (KOB) at the Kiel Fjord (Photo by Mark Lenz)



Figure 2.3. View from the promenade to the benthocosms and information boards (Photo by J. Steffen)

This near-realistic experimental setup has so far enabled many studies of direct and indirect effects of different combined parameters. The scientists developed a model-based simulation in order to summarize the many results, to recognize and to understand higher-level correlations, and to better communicate them within the scientific community. In the following, a short insight into the main findings is given. The composition and the structure of the biotic community are changed, for example, by lower salinity (Barboza et al., 2019; Bommarito et al., 2020) and by the detrimental impacts of heat-waves (Pansch et al., 2018). Alarming shifts from the perennial macroalgae *Fucus vesiculosus* community to annual filamentous algae are reported (Graiff et al., 2020). The scientists particularly identified the effects of the temperature increase as a threat to the population of this ecosystem relevant macroalgae (Graiff, Bartsch, Ruth, Wahl, & Karsten, 2015; Graiff, Dankworth, Wahl, Karsten, & Bartsch, 2017; Wahl et al., 2020). In general, the negative effects of warming are far stronger than those of acidification (Graiff et al., 2017; Mensch, Neulinger, Künzel, Wahl, & Schmitz, 2020; Raddatz et al., 2017; Wahl et al., 2020) and a strong seasonal dependence of the effects were found (e.g. Mensch et al., 2020; Rickert, Lenz, Barboza, Gorb, & Wahl, 2016; Wahl et al., 2020). The identified changes at the ecosystem level may have far-reaching consequences for the provision of important ecosystem services. For example, given the functionality of *F. vesiculosus* as a foundational species and its pending decline, a possible scenario in the year 2100 could result in reduced oxygen production, reduced carbon and nutrient binding capacity, as well as poorer coastal protection and fewer shelter options for fish (Wahl, Molis et al., 2015).

The following illustration (Figure 2.4) shows the effects and the interactions of representative parts of the ecosystem based on the findings of the benthocosm research. The developed outreach activity is based on these findings.

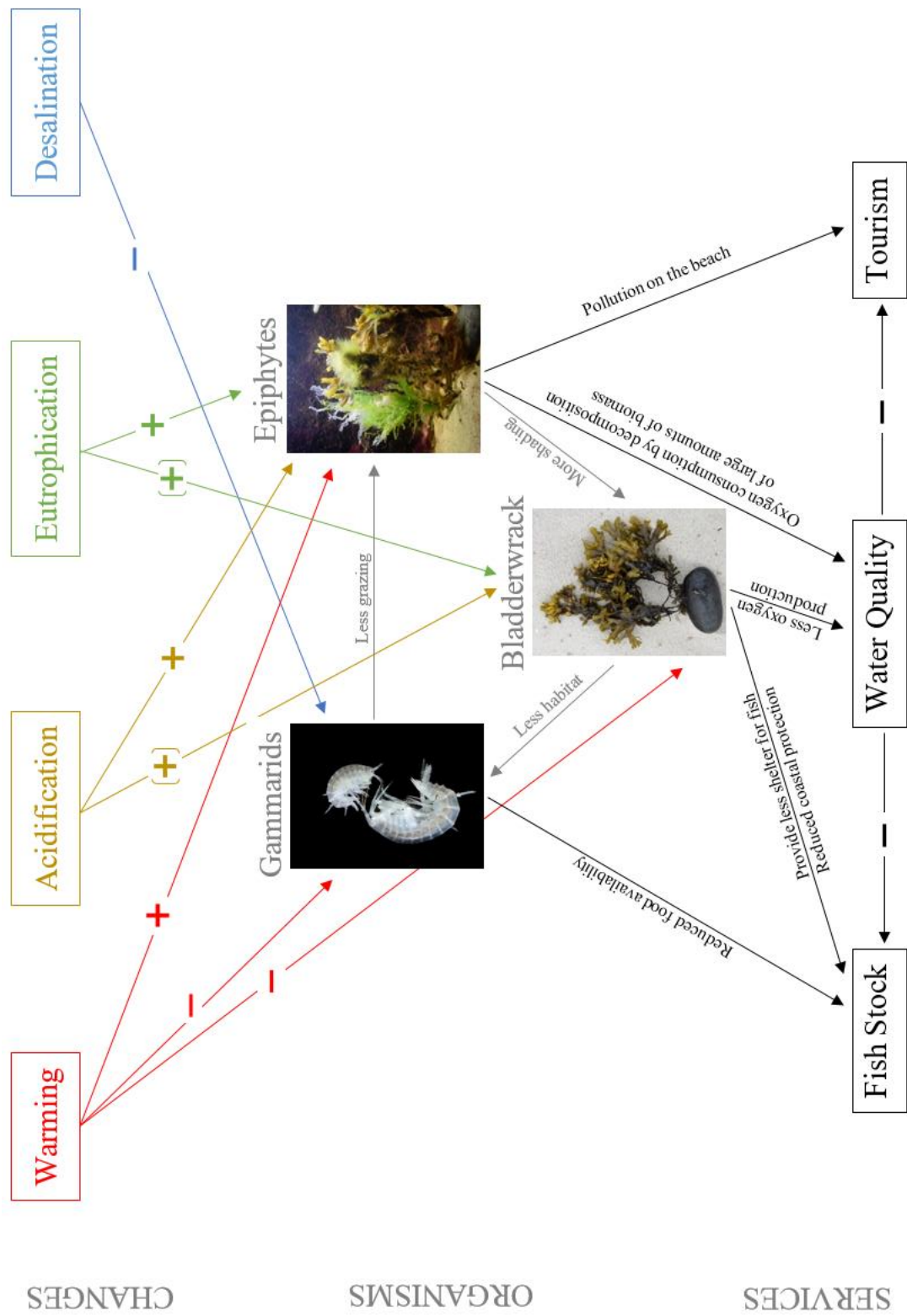


Figure 2.4. Simplified visual diagram of the Future of the Baltic Sea (predicted scenario in 2100): Impacts of the Baltic Sea changes on selected representative organisms and ecosystem services; The **colored** arrows show the effects of the changes on fitness and population size of the organisms; - = negative effects; + = positive effects; The **grey** arrows show the correlation between the organisms; The **black** arrows show the effects of the organisms' changes on ecosystem services, the labels on the arrows indicate the reason for the impact (Photo Gammarids by Daniel Con-Vetterlein; Photos Bladderwrack and Epiphytes by Johanna Krüger)

2.2 CONSIDERATION OF STUDENTS' PERSPECTIVES

The target group of this research was students of Grades 10 to 13 of Gemeinschaftsschulen³ and Gymnasien² in Schleswig-Holstein, Germany. Previous studies on students' perceptions of global change have shown that in some cases there is a) only little knowledge (Bord, O'Connor, & Fisher, 2000; Hansen, 2010; Lombardi & Sinatra, 2012), as well as b) a deficit in the perception of the socio-economic and the political dimensions of vulnerability due to global change (Schuler, 2009). Understanding the causes and effects of the anthropogenic changes is, however, highly relevant for young people so that they can participate as active citizens in future social discussions and thus assume responsibility. This responsibility is apparent, for example, in the political debate on measures to reduce greenhouse gases or minimize nutrient inputs. Misconceptions or lack of knowledge about future changes must be avoided in order to ensure Education for Sustainable Development (ESD) (Schreiber & Siege, 2016). The aim is not to create sorrows or even fear for the future, but rather to promote an understanding of change as a key determinant of students' intentions for action for the future sustainable development of society. The understanding of basic correlations of global change has already proven to be a strong predictor for the willingness to support governmental control and measures, e.g. concerning the reduction of CO₂ emissions (e.g. O'Connor, Bord, Yarnal, & Wiefek, 2002).

In addition to imparting content knowledge, the enhancement of interest in this research area is of great importance, as many different studies confirm the positive correlation between interest and knowledge in a specific field (Höft, Bernholt, Blankenburg, & Winberg, 2019; Krapp & Prenzel, 2011; Schiefele, Krapp, & Winteler, 1992). A fundamentally increased interest of students in environmental topics such as global climate change is evident, for example, as demonstrated by the "Fridays for Future" movement. Actions like these serve primarily to increase interest in the short term, or also called the catch factor (Mitchell, 1993). It is also important to be able to maintain the motivation over longer periods of time (hold factor). This can be achieved, for example, through motivating and comprehension-enhancing learning environments in out-of-school learning locations. Dealing with local topics seems to be especially effective for school students to understand the elusive global correlations and to increase their interest at short-term as well as long-term level. This is due to the relevance of such topics for everyday life which allows a higher identification

³ In Schleswig-Holstein's school system, secondary schools are divided into Gymnasium and Gemeinschaftsschulen. At the Gymnasium, only the highest school qualification can be obtained (Abitur). At the Gemeinschaftsschulen, lower school qualifications can also be obtained. Since there is no suitable translation in English, the terms Gymnasium and Gemeinschaftsschule are used in the following.

with the problems and, therefore, is beneficial for learning and for behavioral change (Elster, 2007). For instance, students from Northern Germany can relate to the organisms in the Baltic Sea from their life at the seaside and are directly or indirectly affected by possible threats. Therefore, teaching the changes in the Baltic Sea seems to be of great importance, especially for students from the Baltic region.

In addition to this overarching relevance of the topic for students, the contents of the outreach activities presented in this doctoral thesis are part of the German curriculum for the subjects chemistry and biology for Grades 10 - 13. The curriculum of both subjects demands the teaching of content-related and process-related skills for the development of scientific literacy. Teaching the changes of the Baltic Sea in particular is not required in the German curriculum. The North Sea and the Wadden Sea are often chosen as exemplary ecosystems in science education. However, the Baltic Sea as the largest brackish water sea on earth offers special and highly interesting aspects for the teaching of underlying (and mandatory) ecological and chemical processes and concepts. The enhancement of content-related competencies through the outreach activities for the subject chemistry can be primarily assigned to the basic concept of chemical reactions with a special focus on the concept of equilibrium reactions (MBWK, 2019). The curriculum recommends teaching marine chemistry respectively ocean acidification as an example for the subject area Chemistry and Environment (MBWK, 2019, p. 57). For biology, several basic concepts are addressed by the above-described science contents (MBWK 2019) (see Table 2.1).

Table 2.1. Localization of the communicated topics in the subject requirements for the subjects chemistry and biology

Subject	Basic concept	Content
Chemistry	Equilibrium concept	Chemical equilibrium Influence on equilibrium reactions pH value
Biology	Compartmentalization	Biosphere, ecosystem, population, organism Specific spatial structures using the example of an ecosystem Seasonal changes
	Control and regulation	Intra- and interspecific relationships Nature Conservation: Preserving Biodiversity
	Material and energy conversion	Producers, consumers, destructors Carbon cycle, nitrogen cycle Food webs Trophic levels

The computer simulation and hands-on experiments conducted in the interventions⁴ also enable the development of process-related skills such as knowledge acquisition skills, communication skills, and evaluation skills. Through authentic insight into scientific research and methods, students' perception of scientific knowledge acquisition is enhanced. The autonomous application of the various scientific methods of knowledge acquisition promotes the development of ways of thinking and working in the fields of biology and chemistry. In both methods, the students must gain information independently, generate hypotheses and knowledge, and, in part, pass on the conclusions in a comprehensible manner in the plenary session. This practical work in small groups aims to promote the students' communication competence. In addition, the participants shall develop evaluation competence by evaluating future scenarios and developing possible options for action.

The use of methods like experiments and computer simulations is important not only because of their educational suitability for knowledge acquisition. They also provide an authentic insight into science with regard to basic concepts and the nature of science (content level) and train students' digital skills (methodic level). A large study on digital literacy shows that German school students still often have only rudimentary skills and basic knowledge in the competent use of new technologies and digital information (Eickelmann et al., 2019). In the future, digital structures will be found in all areas of work and life. Hence, teaching digital skills is very important to prepare students for successful participation in this digitalized society. Thus, the Kultusministerkonferenz (2017) demands in its strategy "Education in the Digital World" that students should learn to work with digital technologies in all subjects. Therefore, modern interactive computer simulations with good instructional support and a high degree of student autonomy in both outreach activities are used (Figure 2.5 and Figure 2.6)⁵.



Figure 2.5. Study I: Students working with the simulation on the computer (Photo by Johanna Krüger)



Figure 2.6. Study II: Students working with the simulation on the tablet (Photo by Tobias Plöger)

⁴ In the following, intervention is used synonymously for outreach activity

⁵ All photographed students have consented to the publication of the photos in a written permission

2.3 DESIGN OF THE OUTREACH ACTIVITIES

Following Leibniz's motto „*theoria cum praxi*“ (Leibniz & Hochstätter, 1987), the outreach activities were developed first and then the evaluation was constructed. In other words, research follows design.

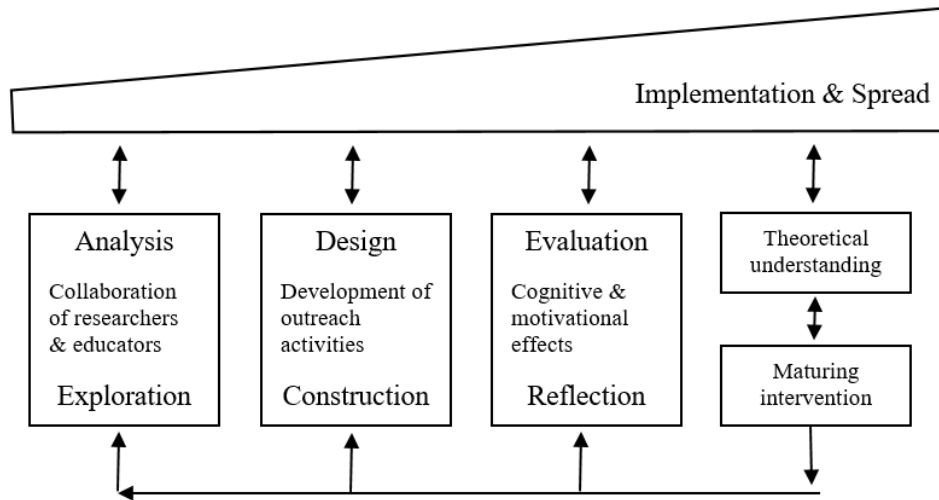


Figure 2.7. Generic model for conducting educational design research (from McKenney & Reeves, 2018)

The design and the evaluation of outreach activities for science education requires a structured approach that includes science as well as students' perspectives and enables continued development. Such a structured methodology is presented in the design-based research (DBR). Design-based research is a four-stage iterative process for the development of educational activities of all kinds (McKenney & Reeves, 2018). According to the model of McKenney and Reeves (2018), the main steps of DBR include: A) analysis and exploration, B) design and construction, C) evaluation and reflection, D) redesign and dissemination. Design-based research is considered as a framework for reflective practice research (Amiel & Reeves, 2008) and for designing authentic learning environments (Bannan, Cook, & Pachler, 2015). The main goal of DBR is the development of transferable design principles (McKenney & Reeves, 2018). The development and evaluation of the outreach activities of this doctoral thesis are based on the process of the DBR approach (Figure 2.7).

2.3.1 Analysis and Exploration of Interdisciplinary Goals

The first step of the DBR approach consists of negotiating the goals for the different groups involved in the project (in this case, the marine ecologists, educators, and media psychologists). Detailed explanations of the communication goals of marine ecologists and educators are already described in Section 2.1 and Section 2.2. A summary of the goals for the outreach activities can be seen in Table 2.2.

Table 2.2. Overview of the goals of marine ecologists, educators, and media psychologists

Goals marine ecology	Goals science education	Goals media psychology
Knowledge transfer about the effects of anthropogenic changes in the Baltic Sea on organism and population level	Imparting knowledge of ecological principles and processes	Identification of the educational advantages and disadvantages of experiments and simulations in direct comparison
Promoting interest in marine ecology	Teaching the understanding of science (Bromme & Kienhues, 2014)	Comparison of the effect of one Versus two methods
Communication of threats for the Baltic Sea ecosystem	Provide authentic insight into science research (Braund & Reiss, 2006)	Investigation of the effects of the sequence of methods in a combined approach
Create awareness for the impacts on society	Presenting evidence-based model predictions with some degree of uncertainty as scientific practice (Allchin, 2011)	Study of the effects on cognitive load
Development of sustainable behavior		
Provide insight into the development and evaluation of model-based predictions	Improving digital competences	

The overall communication goals of the outreach activities can be summarized as follows:

- Imparting content knowledge and promoting interest
- Providing insights into authentic modern science (through the interaction of experiments and model-based simulation)

2.3.2 Design and Construction of Outreach Activities in a Student Laboratory

Student Laboratories as Out-Of-School Learning Locations

For the realization of the mentioned goals, the outreach activities were implemented in a student laboratory (also called student lab). Student laboratories as out-of-school learning locations with close cooperation to research institutions are a suitable learning environment for imparting current research topics in an authentic way (Engeln, 2004). Learning in the student laboratory takes place in authentic labs or rooms with significantly better equipment than in schools and with a sufficiently large number of workplaces. Student labs focus on the students' own experiences, research, and try-outs (Haupt et al., 2013). In comparison to the often inadequate infrastructural conditions for digital education in schools (Eickelmann et al., 2019; Gewerkschaft Erziehung und Wissenschaft [GEW], 2020) and often insufficient digital skills of teachers (Lorenz et al., 2017) student laboratories offer high potential for promoting digital learning.

Visiting a student laboratory is becoming increasingly popular in Germany (Haupt, 2015) so that more than 380 different student laboratories already exist (<https://www.schuelerlabor-atlas.de/>).

They all have the following overall objectives (Engeln, 2004; Engeln & Euler, 2004; Euler, Schüttler, & Hausmann, 2015; Haupt, 2015; Pawek, 2009):

- The enhancement of interest in sciences*
- Promoting the understanding of science*
- Providing insights into the professions and fields of work of scientists (career advancement)
- Conveying a contemporary and authentic image of science* and its importance for society
- Promoting dialogues and discussions on current scientific topics, such as global climate change and ways to counteract it

* Traditionally, “science” includes the fields of mathematics, informatics, natural sciences, and technology (MINT/STEM).

Scientific literacy often is not sufficiently conveyed by regular school lessons alone. For this reason, a student laboratory represents an important contribution to this important goal of science education by promoting students' understanding of science (Guderian, 2007). Furthermore, a high potential of school labs is the promotion of students' interest through an authentic learning environment, a close connection to original research, and a high level of supervision (Engeln, 2004; Glowinski & Bayrhuber, 2011; Pawek, 2009). Besides, teaching authentic science perceptions can have a positive impact on student interest (Stamer et al., 2019). Despite these overarching goals, many student laboratories focus on different aspects. The Federal Association of Student Laboratories e.V. LernortLabor (2020) therefore identified ten different student laboratory categories:

- **Classical student laboratory:** is attended by whole classes or courses as part of school events, where the program offered is closely linked to the content of the curriculum
- **Student research center:** is visited by particularly interested students for long-term autonomous research projects independent of the school
- **Teaching-learning-laboratory:** is intended for the didactic training of university students studying to become teachers. Participation in the student laboratory is part of the curriculum of educational studies
- **Student laboratory for science communication:** focusing on communicating information about current scientific findings and new technologies
- **Student laboratory with a focus on career orientation:** introduce students to specific professions in scientific or technical working areas
- **Student laboratory with a focus on entrepreneurship:** focus on teaching entrepreneurial skills and economic aspects.
- **Student laboratory with a focus on engineering, development, and production:** offers intergenerational opportunities to voluntarily work on technical projects

- **Student laboratory for Humanities / Social and Cultural Sciences:** focuses on the communication of historical and societal topics
- **Mobile student laboratory:** carries out the activities at suitable locations (for example at the educational institution or on the beach, forest, etc.)
- **Student laboratory network:** coordinates a regional or national student laboratory network.

These categories are not mutually exclusive. A student laboratory can fulfill several aspects at the same time and does not have to be strictly assigned to one category.

According to Haupt et al. (2013), autonomous experimentation and independent learning by students should always be the focus, as it promotes interest and motivation in science (Braund & Reiss, 2006; Engeln & Euler, 2004). However, the extent to which inquiry-based learning or guided inquiry takes place depends on whether the questioning, the choice of methods and the interpretation of the results are carried out by the supervisors. Despite the intended investigative experimentation, classical student lab programs are often characterized by structured learning processes guided by experts (Schwarzer & Parchmann, 2018). Completely independent experimenting and researching, on the other hand, takes place in the student research centers, which are visited by interested students in their spare time.

The Kieler Forschungswerkstatt

An example of a classical student laboratory, which focuses on science communication and equally functions as a teaching-learning laboratory and student research center, is the Kieler Forschungswerkstatt (<https://www.forschungs-werkstatt.de/>, Figure 2.8).



Figure 2.8. The logo of the Kieler Forschungswerkstatt

“*Learning. Teaching. Exploring.*” is the motto of the joint student laboratory of the Leibniz Institute for Science and Mathematics Education (IPN) and Kiel University (Christian Albrechts Universität zu Kiel, CAU) (Kieler Forschungswerkstatt, 2020a). The Kieler Forschungswerkstatt (KiFo) serves as Joint Lab of the involved partners in which science-based and research-supported activities are developed and evaluated in an interdisciplinary approach. By now, the Kieler Forschungswerkstatt offers eleven different topic labs for students from Grades 3 to 13 with a focus on the natural sciences and social sciences (e.g. ozean:labor, geo:labor, demokratie:werk, kunst:werk). In the ozean:labor, for example, students explore current topics in marine research such as marine mammals, fishery or the sustainable use of plastic. The close cooperation between scientists from Kiel University and didactic experts of the IPN creates authentic and didactically well prepared

learning environments. Thus, the potential of a student laboratory for authentic science communication can be fully exploited. The location in the Botanical Garden as well as the good technical equipment and detailed interior design make the Kieler Forschungswerkstatt an attractive place for learning (Figure 2.9 and Figure 2.10). Since October 2012, a total of more than 650 school classes have participated in classic one-day student lab activities (Kieler Forschungswerkstatt, 2020b).



Figure 2.9. Exterior view Kieler Forschungswerkstatt (Photo by Anna Thielisch)



Figure 2.10. Sponsoships boards (Photo by Tobias Plöger)

The Outreach Activities

Within the first objective, two new outreach activities associated with the ozean:labor were designed. They were developed sequentially and build on each other. For each outreach activity, an evaluation was conducted (termed as Study I and Study II). The associated questionnaires and working materials can be found in Appendix A and Appendix B. Differences and similarities of the interventions are explained in the following.

The first intervention based on an existing simulation and aimed only at the comparative investigation of the two methods regarding one single topic. Thereupon, the second intervention based on an own optimized design of a simulation and was more complex with regard to the topic (several changes, different organisms) as well as the research questions (comparison of the methods, combination of the methods, sequence effects).

In the first intervention, students worked on either an experiment or a computer simulation after a joint introduction. The subject matter was ocean acidification (causes, process, and effects on calcifying organisms). In the second intervention, students worked with a combination of both methods. The topic was about changes in the Baltic Sea (warming, acidification, eutrophication and salinity shifts), their effects on the ecosystem and social consequences. The first outreach activity was implemented at school as a mobile student laboratory. The second activity took place as a regular student lab day in the Kieler Forschungswerkstatt. For an overview over the two outreach activities see Table 2.3.

Table 2.3. Overview of the two outreach activities (Exp. = Experiments, Sim. = Simulation, Gem.= Gemeinschaftsschule, Gym. = Gymnasium)

	Outreach Activity I	Outreach Activity II
Location	School	Student laboratory
Topic	Ocean acidification and impacts on calcifying organisms (one-dimensional)	Four changes of the Baltic Sea and their impacts on ecosystem and societal level (multidimensional)
Content	pH-value, reasons for and extent of the increase in global atmospheric carbon dioxide (CO ₂) concentration, equilibrium reaction of CO ₂ in seawater and the effect of acidification on calcifying organisms	Warming, eutrophication, salinity and ocean acidification of the Baltic Sea and impacts on bladderwrack, gammarids and epiphytes, their interactions and challenges on the ecosystem and society
Duration	90 minutes	180 minutes
Design	1. Pre-test (20 min) 2. Introduction (20 min) 3. Practical work: exp./sim. (30 min) 4. Post-test (20 min)	1. Pre-test (15 min) 2. Introduction (30 min) 3. Practical work I: exp./sim. (60 min) 4. Practical work II: sim./exp. (60 min) 5. Post-test (15 min)
Participants	24 classes 1/3 Gem., 2/3 Gym. $N = 443$ ($N_{exp} = 221$, $N_{sim} = 222$) Grade: 10-13 Average age: 17.58 years	29 classes 1/3 Gem., 2/3 Gym. $N = 367$ ($N_{exp} = 198$, $N_{sim} = 169$) Grade: 10-13 Average age: 17.02 years

The exact procedure of the two interventions is already described in detail in Manuscript I. See the working materials in Appendix B for a detailed description of the procedure of the different stations. Therefore, the design of the methods are only briefly described here, focusing on the content implementation.

Outreach Activity I

Teaching of ocean acidification in secondary school classes is recommended in the curriculum as reported. In a short introduction, the basic causes of the process of acidification were explained to ensure that all students got similar basic information. Afterwards a video of a study on ocean acid-



Figure 2.11. Left: Students watching video on ocean acidification, Right: QR-Code video ocean acidification GEOMAR, URL: <https://www.youtube.com/watch?v=U7UbKSvenZY>

ification in Spitzbergen conducted by scientists of the GEOMAR offered insights into current research (Figure 2.11). The 5-minute video showed research on mesocosms, which are complex setups similar to benthocosms, where changes on whole communities can be studied under realistic conditions. Afterwards the class was randomly divided into two groups. One half worked in small groups on an experiment, which was developed by scientists of the GEOMAR in the context of the project BIOACID (Biological Impacts of Ocean Acidification) (BIOACID, 2012). The model experiment clearly demonstrated the effects of increased CO_2 concentrations in the atmosphere on the pH value of seawater and revealed its buffer effect. For this purpose, two small tanks with equal volumes of distilled water and seawater were each equipped with a pH meter. Candles were distributed around the tanks and finally the whole setup was covered with an aquarium. The distilled water served as a control to the seawater, the candles represented the burning of fossil fuels, and the aquarium represented the atmosphere. The students observed that the pH value of seawater decreased less rapidly than that of distilled water. With the help of the equilibrium reaction equation of CO_2 in seawater, they elaborated the reason for this buffer effect. A supervisor was permanently available for technical and content related questions. Afterwards the students concluded the effects of acidification on calcifying organisms using the reaction equation.

The other half of the class worked on a simulation that was provided by Stanford University (Figure 2.12). The key element of this digital learning environment is an interactive simulation. The students were able to observe changes in the equilibrium reaction of CO_2 in seawater at different assumptions of atmospheric CO_2 concentration. Simultaneously, they were able to observe the resulting effects on calcifying organisms: Depending on the available calcium ions, the chalk structure of the drawn coral became stronger or weaker. Finally, the students examined the calcification process and drew conclusions as to why acidification will have negative effects on such organisms. Finally, open questions were clarified and options for action were jointly developed to slow down the process of ocean acidification.



Figure 2.12. Left: Student working on the simulation (Photo by Johanna Krüger); Right: QR-Code simulation ocean acidification, URL: https://depts.washington.edu/i2sea/AcidOcean/AcidOcean_DE.htm

Outreach Activity II

The second interdisciplinary developed intervention was the student laboratory day called "Future of the Baltic Sea". During the full-day program, the development and interaction of experiments and model-based simulations in science were highlighted in addition to the main focus of the content. The purpose of this intervention was to convey the processes of major environmental impacts of the Baltic Sea (warming, eutrophication, acidification and salinity changes) and its effects on representative organisms of the ecosystem (gammarids, bladderwrack, and epiphytes) as well as the resulting challenges for the whole system (water quality, fishing, tourism). In an introductory lecture, students were given an overview of the anthropogenic influences on the ocean and possible future global changes. Therefore, the work of the Benthic Ecology research group was presented and the reasons why the Baltic Sea is considered a promising research area was explained. Then the class was randomly divided into two groups. One group worked first on the experiments and then on the simulation, the other group did it the other way around. The combination of methods in this outreach activity was intended to reflect the combination of scientific methods in modern research. The division of the class into different sequences of the method was chosen for evaluation reasons (further explanations in Section 2.3.3 as well as in Section 4 and 5).

In interdisciplinary collaboration, four experiments were conducted, one each on the topics of warming, acidification, eutrophication and salinity changes in the Baltic Sea. Since only one process with its effects on one group of organisms can be represented by experiments at a time, the experiments each represent the most relevant changes.

For the experiment on **warming**, the students investigated the fitness of the bladderwrack depending on the water temperature. The students determined the fitness by calculating the rate of photosynthesis through the measured oxygen production of the algae. For this purpose, they kept equal sized pieces of bladderwrack in three different water temperatures for 30 minutes (Figure 2.13). The difference between the oxygen concentration measured before and after the test period gave information about the photosynthesis efficiency of the bladderwrack. Considering the learned importance of the macro algae for the ecosystem, the students then discussed the effects and possible solutions.

The **acidification** experiment used titration to measure the calcium content of differently acidified seawater (Figure 2.14). For a direct everyday context on the subject of carbon acids, the students prepared the acidified water samples using a soda stream. Based on the equilibrium reaction equation, the students then evaluated the effects of the lower availability of calcium ions on the calcification process of numerous marine organisms. Finally, in a joint discussion, they developed options for dealing with the problem.

In the **eutrophication** experiment, the students investigated algae growth as a result of available nutrient concentrations. Algae growth was measured by photometric analysis of the chlorophyll a content in different seawater samples. In comparison, one sample was taken near an agricultural drainage site and one at a swimming beach. After the photometric measurement the students calculated the absorption coefficient and thus determined the degree of eutrophication. After elaborating the eutrophication process (Figure 2.15), the students discussed possible ecosystem and social impacts and developed options for action to deal with this problem.

The experiment on possible future changes of **salinity** in the Baltic Sea shows the effects of different salinity levels on the survival rate of gammarids (amphipods). Therefore, the same number of gammarids are kept in different salinity levels over a longer period of time. First, the students learned about the origin of the salinity of the Baltic Sea using an inflow model. Then they investigated the mortalities of the gammarids (Figure 2.16) in dependence of different salinity levels (North Sea 30g/liter, Baltic Sea today 17 g/liter, Baltic Sea of the future 10 g/liter). The assumed salinities of the Baltic Sea represent average values and apply exemplarily to the Bay of Kiel. With the help of a current distribution map of different Baltic Sea organisms, the students analyzed possible effects of lower salt content on the distribution of the gammarids and possible consequences for the food web. Finally, the students also developed options to counteract this change.



Figure 2.13. Students prepare three different temperature approaches with bladderwrack (Photo by Tobias Plöger)



Figure 2.14. Students perform a titration (Photo by Tobias Plöger)



Figure 2.15. Students working out the eutrophication process with the help of a diagram (Photo by Tobias Plöger)



Figure 2.16. Students counting the mortalities of gammarids in different salt concentrations (Photo by Tobias Plöger)

The **simulation** allowed the students to examine the four changes in combination and analyze the effects on the organisms with regard to their interactions (Figure 2.17). The model simulation developed by the Benthic Ecology Research Group for the Scientific Communication Process served as the basis for the student simulation. For the technical realization the Kiel-based company PixlScript was assigned, which was already familiar with designing and developing learning environments. The result was a digital learning environment in the form of a website in which the newly designed simulation was embedded. In this learning environment, the students first had to learn the basics about the different changes and organisms. After that, the interactive mode was activated. The students could then modify the changes using a slider and observe in real time the effects on the three organisms in the middle of the simulation.



Figure 2.17. Left: Screenshot of the simulation "Future of the Baltic Sea", Right: QR-Code of the website for the student lab day with the embedded simulation, URL: <https://ostsee-der-zukunft.experience-science.de/start.html>

With the help of the digital instructions, they investigated various scenarios guided by hypotheses. First, the students had to investigate the effects of individual changes on the three organisms (gammarids, bladderwrack, epiphytes). Then, different combinations (e.g., acidification and warming) followed. Finally, the students analyzed the effects of all three changes in combination as well as the resulting societal impacts. The students each had their own tablet but working in small groups was allowed (Figure 2.18). Group discussions were held at regular intervals to discuss and deepen the results (Figure 2.19). In a final group discussion, the students assessed the effects on the ecosystem and society and developed options for action.



Figure 2.18. Students working on the simulation in small groups (Photo by Tobias Plöger)



Figure 2.19. Group discussion during the simulation (Photo by Tobias Plöger)

2.3.3 Empirical Evaluation and Reflection

The impact of interventions at student laboratories has already been investigated many times. The effectiveness of student lab days in terms of interest development (Budke, 2019; Engeln, 2004; Glowinski, 2007; Guderian, Priemer, & Schön, 2006; Pawek, 2009; Zehren, Neber, & Hempelmann, 2013), knowledge acquisition (Glowinski, 2007; Scharfenberg, 2008), motivation (Brandt, 2005; Schwarzer & Parchmann, 2015; Zehren et al., 2013), or the self-concept of competence (Budke, 2019; Engeln, 2004; Pawek, 2012; Weßnik, 2013) has therefore been investigated. A comprehensive overview of previous dissertations and investigations of the effectiveness of student laboratories can be found at <https://www.lernortlabor.de/ueber-schuelerlabore/literatur>.

This doctoral thesis did not focus on the effectiveness of an entire student lab day like classical student lab research. Instead, the main emphasis was on investigating the effects of the different methods in comparison and combination. Nevertheless, in order to make an (innovative) contribution to basic student lab research, the effects of the outreach activities were investigated on subjective beliefs that have not been considered so far. In line with the above-mentioned goals of the various involved groups in the design process (Section 2.3.1), the following research foci and associated research questions emerged. For a detailed description of the assumed hypotheses, results and conclusions please refer to the corresponding manuscripts and/or sections of this doctoral thesis.

Overarching research foci and research questions of the doctoral thesis:

Research Focus I: The comparative study of cognitive and motivational effects of science-based experiments and computer simulations.

- To what extent do interactive computer simulations / hands-on experiments contribute to an increased content knowledge and situational interest of the students?

➔ Section 4 and Section 5

Research Focus II: The investigation of cognitive and motivational effects of the combination of hands-on experiments and computer simulations as well as sequence effects.

- In which way is a combination of methods better suited compared to the single use of methods to increase content knowledge and situational interest?

➔ Section 5

- What sequence of methods (1st Experiments + 2nd Simulation or 1st Simulation + 2nd Experiments) is preferable to increase content knowledge and situational interest?

➔ Section 5

Research Focus III: Research on the effects of outreach activities on students' beliefs regarding science.

- To what extent do the outreach activities affect students' trust in science?
→ Section 6
- What level of credibility do the students have in the different methods?
→ Section 7.2
- To what extent do the outreach activities affect concepts about scientific predictions?
→ Section 7.3

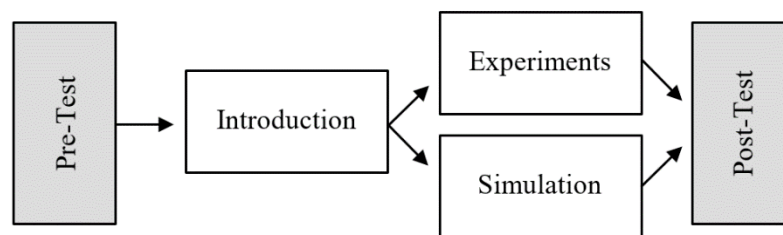


Figure 2.20. Evaluation design of the first intervention (comparison of the methods)

Two different evaluation designs were developed to investigate the research questions. The same structure of the two methods in the first intervention allows a high degree of comparability of the effects of the methods. Therefore, a classic experimental pre-post design was chosen (Figure 2.20).

In the second intervention, one half of the participants worked first on the experiments and second on the simulation, and the other half did the opposite. This allowed findings on the effects of the sequence of methods. An intermediate test was used to control the effects of the individual methods (Figure 2.21).

Based on previous student lab research (see above) and research on experiments and simulations as learning methods (see Manuscript I and Manuscript II), the evaluation was focused on the development of knowledge, interest and cognitive load. In addition, the development of trust in science, credibility of methods, and concepts about scientific predictions were measured (Table 2.4).

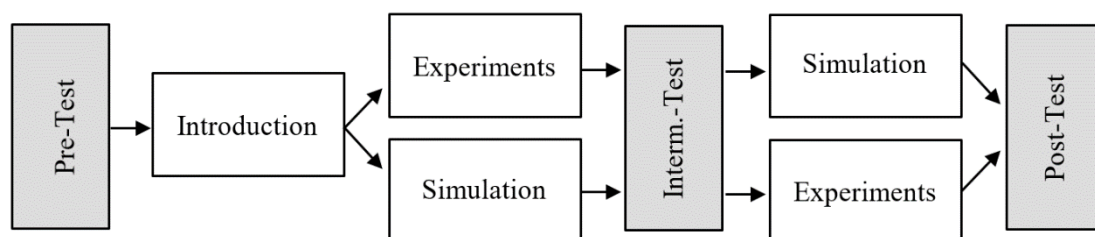


Figure 2.21. Evaluation design of the second intervention (combination of the methods)

Table 2.4. Overview of the used instruments in first intervention (I) and second intervention (II)

	Instruments	I	II
Dependent variables	Content knowledge (self-developed instrument)	✓	✓
	Situational interest (adapted from Engeln, 2004)	✓	✓
	Trust in science (Nadelson et al., 2014)	✓	✓
	Credibility of the methods (self-developed instrument)	-	✓
	Concepts about scientific predictions (self-developed instrument)	-	✓
Independent variables	Personal data (age, gender, marks, type of school)	✓	✓
	Individual interest biology & chemistry (adapted from Frey et al., 2009)	✓	✓
	Prior knowledge (self-developed instrument)	✓	✓
	Cognitive load (Paas, Tuovinen, Tabbers, & van Gerven, 2003)	✓	✓
	Media use in science classes (self-developed instrument)	-	✓

The implementation and results of the empirical research of the two interventions are presented in three manuscripts and are complemented by further results in Section 7. For a detailed insight into the questionnaires, see Appendix B.

2.3.4 Redesign and Dissemination

The fourth element of the design-based research approach is to derive a theoretical understanding from the empirical findings and to incorporate the conclusions into practice as well as into the scientific communication process. The adaptations of the design of the interventions as well as comprehensive implications are explained in the discussion in Section 8.

3 STUDY-BASED IMPLEMENTATION

This section presents an overview of three manuscripts that represent the empirical implementation of the objectives and research questions derived above. The first two manuscripts represent the core-part of this thesis. In consecutive investigations, they address the fundamental research questions of this work (Section 2.3.3). The first manuscript compares the motivational and cognitive effects of experiments and simulations. Subsequently, the second manuscript examines the effects of the combination of these two learning methods. The third manuscript contributes to the basic student lab research by investigating the outreach activities regarding the development of trust in science.

3.1 MANUSCRIPT I: TWO COMPARATIVE STUDIES OF COMPUTER SIMULATIONS AND EXPERIMENTS AS LEARNING TOOLS IN SCHOOL AND OUT-OF-SCHOOL EDUCATION

Status: published in Instructional Science (2022), DOI: 10.1007/s11251-021-09566-1

Co-authors: Tim Höffler (conceptualization, formal analysis, review & editing), Martin Wahl (software, science resources), Katrin Knickmeier (infrastructural resources, science resources), Ilka Parchmann (conceptualization, methodology)

Content: This paper presents the results of the comparative studies of the first intervention (Study I) and the intermediate-test of the second intervention (Study II). With a number of participants of $N_{Study\ I} = 443$ und $N_{Study\ II} = 367$ these studies compare working on computer simulations versus experiments in terms of content knowledge growth, development of situational interest and cognitive load. The results show a higher learning outcome for students working on computer simulations than while working on experiments, despite higher cognitive load. However, working on experiments promoted situational interest more than computer simulations. The paper discusses the resulting potential uses in science education of both methods. Finally, it is recommended that the most effective way to communicate complex current research topics might be a combination of both methods.

3.2 MANUSCRIPT II: A COMBINATION OF HANDS-ON EXPERIMENTS AND INTERACTIVE COMPUTER SIMULATION AS LEARNING TOOLS IN OUT-OF-SCHOOL SCIENCE EDUCATION

Status: in preparation for re-submission

Co-authors: Tim Höffler (conceptualization, formal analysis, review & editing), Katrin Knickmeier (infrastructural resources, science resources), Martin Wahl (software, science resources), Ilka Parchmann (conceptualization, methodology)

Content: This paper presents the investigation of educational effects of a combination of experiments and simulations as learning tools in out-of-school science education. Focusing on content knowledge, cognitive load, and situational interest, one method versus the combination of methods was tested, as well as sequence effects of the combined approach were investigated. Results of the empirical study ($N = 367$) indicated that two methods are better than one for teaching content knowledge but not necessary in terms of situational interest or cognitive load. Results further implicate that experiments have a complementary suitability for simulations in terms of conveying basic knowledge. The paper recommends a combination of first experiments and second simulation, to obtain the best advantages in achieving a comprehensive understanding and the necessary interest for active participation and engagement in societal discussions. The findings implicate that a combination of both methods might be a successful learning tool in science education, as it seems to be particularly useful for communicating current complex scientific topics to students.

3.3 MANUSCRIPT III: HOW MUCH DO STUDENTS TRUST IN SCIENCE? A STUDY OF TRUST IN SCIENCE AND SCIENTISTS AMONG SECONDARY SCHOOL STUDENTS IN OUT-OF-SCHOOL LEARNING ACTIVITIES

Status: published in International Journal of Science Education, Part B (2022), DOI: 10.1080/21548455.2022.2045380

Co-authors: Tim Höffler (formal analysis, review & editing), Ilka Parchmann (conceptualization, methodology)

Content: The paper shows the investigation on the impact of the two outreach activities on the development of trust in science among secondary grade school students. Therefore, the “trust in science and scientists inventory” (TSSI) by Nadelson et al. (2014) had to be first adapted and validated to the use with secondary school students. The use of the adapted instrument shows that the mean level of trust in science among school students is similar to the level among university students. A trust-enhancing effect of the interventions could only be found for students with low prior level of trust. However, there is evidence that a high level of trust in science can support learning in science outreach activities. The paper concludes that there might be no general lack of trust in science among senior grade school students. However, the enhancement of trust should still be promoted especially the increase of the level of low-trustors is important to prevent negative social tendencies.

4 TWO COMPARATIVE STUDIES OF COMPUTER SIMULATIONS AND EXPERIMENTS AS LEARNING TOOLS IN SCHOOL AND OUT-OF-SCHOOL EDUCATION

4.1 ABSTRACT

Interactive computer simulations and hands-on experiments are important teaching methods in modern science education. However, previous studies could not sufficiently clarify the educational advantages and disadvantages of both methods and often lack adequate comparability. This paper presents two studies of direct comparisons of hands-on experiments and interactive computer simulations as learning tools in science education for secondary school students. The investigation was conducted in two different learning locations to prove the independence of the findings from the learning location (Study I: school; Study II: student laboratory). Using a simple experimental research design with type of learning location as between-subjects factor ($N_{Study\ I} = 443$, $N_{Study\ II} = 367$) these studies compare working on computer simulations versus experiments in terms of content knowledge growth, development of situational interest and cognitive load. Independent of the learning location, the results showed a higher learning success for students working on computer simulations than while working on experiments, despite higher cognitive load. However, working on experiments promoted situational interest (especially the epistemic and value-related component) more than computer simulations. The findings reviewed in this paper imply that the most effective way to communicate complex current research topics might be a combination of both methods. These conclusions derive a contribution to successful modern science education in school and out-of-school learning contexts.

4.2 INTRODUCTION

Many highly relevant but difficult to communicate topics with social relevance (socioscientific issues) exist in science education. It is a great challenge for learners to grasp these complex processes and concepts, especially when several aspects require simultaneous consideration, for example regarding the intricate topic of climate change. Interactive computer-based methods might help promote the acquisition of knowledge and understanding in such contexts in a comprehensive manner. Interactive computer simulations (in the following only referred as computer simulation or simulation) become a more and more important element of teaching in science education, especially in subjects such as chemistry, biology, or physics (Rutten et al., 2012). Compared to simple animations,

computer simulations allow the learners to actively interact with the simulated scenario by changing given parameters according to their own ideas and subsequently receive direct feedback from the system. The underlying mathematical model determines how the computer simulation reacts to the parameter changes of the learner, which shows the influence of a certain aspect on the process and the outcomes (Develaki, 2017; Lin, Liu, & Sweller, 2015). The fact that computer simulations represent a model of a system (natural or artificial) or a process (Jong & van Joolingen, 1998) with all its determining parameters enables the learner to safely experiment and simulate in an artificial learning environment (Lin et al., 2015). Indications already suggest that they are particularly suitable for communicating complex issues (Smetana & Bell, 2012) and are able to improve overall science skills (Siahaan, Suryani, Kaniawati, Suhendi, & Samsudin, 2017). Unfortunately, computer simulations as learning tools often lead to a high cognitive load (Paas, Renkl et al., 2003) and in some cases do not produce the expected learning success (Jong, 2010; Köck, 2018). The increased time required for the introduction of such a method, the lack of know-how as well as financial and material resources of the educational institution are factors limiting the use of computer simulations in school and out-of-school education.

Instead, the so-called hands-on experiment is a common educational method widely used by educators in various fields to convey a wide range of concepts and processes. Hands-on experiments are often used methods to communicate scientific processes and concepts in science education (Di Fuccia, Witteck, Markic, & Eilks, 2012; NRC, 2012; NSTA, 2013). In scientific research, experiments are hypothesis-driven and usually open-ended. In contrast, experiments for educational purposes simulate already concluded scientific questions new to the students. The students work on a scientific question alone or in small groups developing their own hypotheses, testing these with experiments and interpreting the results in relation to their hypotheses. The experiments used in our investigations are theory-based and model experiments. A model experiment is an experiment with a material model that differs in at least one characteristic from the represented original, due to reasons of availability, complexity, hazard potential, accessibility, or cost (Sommer et al., 2017). In particular basic processes and concepts can vividly be conveyed with laboratory experiments (Köck, 2018). However, they often do not adequately reflect current questions and investigations (Braund & Reiss, 2006) and fall short when teaching complex concepts.

Shouldn't educators use simulations instead of traditional hands-on experiments especially when communicating complex and current socio-scientific issues? Which advantages and disadvantages do the two methods offer in comparison to each other? To answer these questions, a review of the current literature on these two methods in terms of their cognitive and motivational effects is necessary. We will therefor present the influence of simulations and experiments on knowledge, cognitive load and the development of interest in the following.

4.3 THEORETICAL BACKGROUND

The processing of computer-based simulations and hands-on experiments in science education causes different effects on the cognitive and motivational level, for example regarding content knowledge acquisition, cognitive load, and interest.

4.3.1 Content Knowledge

The improvement of content knowledge is still one of the most important parameters when evaluating educational activities. Although its assessment is less important in science communication, it is a common measurement in the field of science education (Baram-Tsabari & Osborne, 2015). We could not find a general consent on the educational impact and effects of computer simulations and hands-on experiments on knowledge acquisition.

On the one hand, empirical studies indicate that computer simulations foster students' involvement in the observation and investigation of phenomena, which supported students' conceptual change in science (Rutten et al., 2012; Trundle & Bell, 2010). For instance Park (2019) found that after working on a computer simulation on physical concepts, the students predicted and explained the given scientific phenomena with more valid scientific ideas. Especially for the communication of complex processes several studies point to the potentially highly effective suitability of simulations (Sarabando, Cravino, & Soares, 2016; Smetana & Bell, 2012). Conversely, the meta-study of Hattie (2012) showed only low effects regarding the influence of computer simulations and simulation games on the learning success ($d = 0.33$). In addition, empirical studies report several cognitive and metacognitive difficulties for students learning with computer simulations (Jong, 2010; Jong & van Joolingen, 1998; Köck, 2018; Mayer, 2004) mostly due to the high level of cognitive load. In particular the lack of interactivity can lead to learning only rudimentary content (Linn, Chang, Chiu, Zhang, & McElhaney, 2010).

Findings regarding the influence of hands-on experiments on students' learning outcomes are also inconclusive. Some authors consider experiments in science education to be of great importance with regard to the acquisition of knowledge (Hofstein & Lunetta, 2004). Hands-on activities improve students' academic achievement and understanding of scientific concepts through the manipulation of real objects, as abstract knowledge can be communicated more concretely and clearly (Ekwueme, Ekon, & Ezenwa-Nebife, 2015). Working on hands-on activities increases the students' ability to interpret data and think critically (Tunnicliffe, 2017). According to Hattie (2012) a medium effect for learning with experiments could be found ($d = 0.42$). However, not all authors agree with the positive influence of experiments on learning outcomes. Students often have major problems working systematically and strategically (Jong & van Joolingen, 1998). Additionally, school experiments often present reconstructions and simplifications of past knowledge processes and

might not adequately reflect today's issues and investigations (Braund & Reiss, 2006). Thus, realistic conceptions about research often cannot be developed.

4.3.2 Cognitive Load

Cognitive load theory (see van Merriënboer and Sweller (2005) for an overview) claims that successful learning can only occur when the (limited) cognitive capacities of learners' working memory system are not overburdened. A cognitive overload is likely to occur especially in cases of very difficult tasks (high intrinsic cognitive load) in combination with inappropriate and overly complex instructional designs (high extraneous cognitive load), which results in low learning outcomes (Mayer et al., 2005).

The cognitive effort required when working in multimedia learning environments (like a computer simulation) is usually high (Anmarkrud, Andresen, & Bråten, 2019; Mutlu-Bayraktar, Cosgun, & Altan, 2019). In a simulation, students must consider several aspects simultaneously. This requires learners to understand the nonlinear structure of the learning environment, which "costs" some cognitive resources (high intrinsic cognitive load). Understanding the complex underlying systems and processes of a computer simulation is often a great challenge especially for learners with low prior knowledge (Jong, 2010; Jong & van Joolingen, 1998). What is more, by encouraging learners to manipulate too many variables, simulations might generate split-attention effects (having to keep in mind many elements or having to observe several changes on different places on the screen) (Kalyuga, 2007). Especially simulations without guidance/instructional support tend to cause learners' disorientation and thus lead to extraneous cognitive load. These high cognitive demands of simulations often lead to a cognitive overload (Paas, Renkl et al., 2003) which results in a more difficult understanding and low learning outcomes (Mayer et al., 2005). Therefore several studies have shown the effectiveness of instructional support for learning with computer simulations to prevent cognitive overload (Eckhardt, Urhahne, & Harms, 2018; Jong & van Joolingen, 1998; Rutten et al., 2012).

4.3.3 Interest

In educational research two types of interest can be differentiated – situational and individual (Krapp, Hidi, & Renninger, 1992). Individual interest is a relatively permanent predisposition attending objects, events or ideas and deals with certain contents (Renninger, 2000). Situational interest is mainly caused by situation-specific environmental stimulations like novel or conspicuous activities (Lin, Hong, & Chen, 2013). Both types of interest are characterized by three aspects: an emotional, a value-related and a cognitive component (e.g. Engeln, 2004; Krapp, 2007). In our study, the cognitive component of situational interest is mainly concerned with a person's need to increase competence, knowledge and skills in relation to the object of interest. Therefore, we will call this aspect epistemic component in the following.

Extensive research exist on changing motivation and interest by using computer simulations as learning tools. Hence, in several studies increased interest (e.g. Jain & Getis, 2003) as well as the motivating effect of computer simulations (Rutten et al., 2012) were observed. Both a high level of interactivity and the possibility of exercising control over the learning environment increase motivation for the subject matter even more.

With less attention than in research on simulations, an increased interest in processing experiments was also observed (Palmer, 2009).

4.3.4 Previous Comparative Studies

Despite a few studies already directly compared digital and hands-on methods a clear trend with regard to educational advantages and disadvantages cannot yet be determined. Some studies show advantages of experiments regarding learning outcomes (Kiroğlu, Türk, & Erdoğan, 2019; Marshall & Young, 2006), while other studies found advantages regarding learning effects in digital simulations (Lichti & Roth, 2018; Paul & John, 2020; Scheuring & Roth, 2017). Berger (2018) for example, observed a higher motivation of the students when working on the computer-based physics experiment compared to an experiment.

Other studies, in turn, could not find a clear trend in either direction (Lamb, Antonenko, Etopio, & Seccia, 2018; Stull & Hegarty, 2016). For example, Zendler and Greiner (2020) showed in a direct comparison of experiments and simulations in chemistry education no general difference in students' learning outcomes on reactions of metals.

4.3.5 Summary

Interactive computer-based simulations generally have a motivating effect and promote students' interest. However, computer simulations often do not generate the expected learning success due to a high level of cognitive load. Hands-on experiments thus convey basic concepts and processes in particular, but are less suitable for presenting current and complex topics. Hence, computer simulations may be of help here. Existing comparative studies do not yet show any clear trend regarding the advantages and disadvantages of these methods.

4.4 THE PRESENT STUDY

The current paper is part of the Leibniz ScienceCampus Kiel Science Outreach Project (KiSOC), which aims to investigate success factors for an understandable and motivating communication of the meaning and results of science. For this purpose, the KiSOC investigates various conceptions and effects of different outreach activities. A key aspect of a Leibniz ScienceCampus is the close cooperation between Leibniz institutions and universities, which gives this project its special character of an interdisciplinary collaboration between marine ecology research, research in chemistry

education, and media psychology. We combined didactic and media-psychological aspects to gain a deeper understanding of motivational and cognitive effects of the different methods.

This paper presents findings of two studies offering direct comparisons of hands-on experiments and interactive computer simulations as learning tools for students from Grade 10 to Grade 13. The two studies investigated the effects of working on these learning methods focusing on content knowledge achievement, cognitive load and changes in situational interest. Due to the fact that the investigations were identical in terms of design and procedure, they show a high degree of comparability. The first study took place in school and the second study in a student laboratory to confirm the independence of the results from the learning location. Climatic and anthropogenic changes in marine ecosystems served as subject matter.

4.4.1 Why Another Comparative Study?

Most of the existing comparative studies in this research field show the difference between teaching with simulations vs. teaching without simulations (e.g. as presented in the detailed review by Rutten et al. 2012). Thus, the many different factors of instruction, such as reading textbooks, completing tasks, classroom discussions, or different group sizes, can hinder a valid measurement of the effects of the methods. This leads to a lack of comparability. Our study focused on the direct comparison of the methods, independent of the lessons' context. The external factors are therefore stable: same introduction, structure of the instruction unit and same topics, only the learning methods were different. This allows us to make conclusions about the effects of the methods itself. In addition, there are some comparative studies in a laboratory context focusing on laboratory work with vs. laboratory work without the use of simulation (Rutten et al. 2012). Even here, reliable conclusions about the effect of the individual methods cannot be clearly defined due to possible transfer effects between the methods. However, since the methods are not combined in our studies, it is possible to make better statements about the effect of the single methods. A few known studies exist with a direct comparison of the two methods primarily in the fields of physics or chemistry education (e.g. Chang et al 2008), focusing on the comparison of virtual vs. analogous experiments of low complexity. Our study presents a comparison of differently performed experiments with the same content and high complexity. Compared to the existing comparative studies, our studies show a high sample size ($N_{Study\ I} = 443$; $N_{Study\ II} = 367$; $N_{total} = 810$). For example, the 60 studies presented in the detailed review by Rutten et al 2012 had an average sample size of 160 participants. Thus, current findings on learning with interactive computer simulations and hands-on experiments do not yet provide sufficient insights into cognitive and motivational processes of learning on socio-scientific issues with high complexity. The studies presented here address this desideratum and aim to close this gap.

4.4.2 Research Questions and Hypotheses

The research questions and corresponding hypotheses of this project are presented in the following.

a) To what extent do interactive computer simulations / hands-on experiments contribute to an increased content knowledge? How do both methods differ?

We expected that both methods would improve students' content knowledge, since the topic was new to most of them and both experiments (Ekwueme et al., 2015; Tunnicliffe, 2017) and simulations (Rutten et al., 2012; Smetana & Bell, 2012) have been shown to promote learning. We further expected less content knowledge achievement from working with the computer simulation than from the experiments, especially because of the higher cognitive load resulting from work on the simulation (Mayer et al., 2005).

b) To what extent do interactive computer simulations / hands-on experiments affect cognitive load while completing the tasks? How do both methods differ?

We expected a medium students' cognitive load for both methods. Both methods had instructional support, which has been proven to reduce learners' extraneous cognitive load (Eckhardt et al., 2018). We tried to adapt the level of content knowledge to the participants' skills in order to reduce intrinsic load. However, we expected a low level of prior knowledge of the students, since the topic addressed was not a mandatory topic in the German curriculum, which could have a negative impact on the intrinsic cognitive load (Jong, 2010; Jong & van Joolingen, 1998). Furthermore, we expected that the participants had different cognitive skills, since they came from different schools and grades and also will not be used to work on computer-based learning environments since this educational method is still not common in German science classes. This can lead to an overburdening with the complex structures, especially for the simulation (Jong, 2010). Therefore we expected higher cognitive load when working with the computer simulations compared to working with the experiments.

c) To what extent do interactive computer simulations / hands-on experiments increase situational interest of the students? How do both methods differ?

We expected an at least medium level of situational interest for both methods since both methods provide evidence of a general motivating character (Palmer, 2009; Rutten et al., 2012). In particular, through the work on computer simulations we expected a higher increased situational interest because of the motivation character of a digital medium. These hypotheses applied to all subscales of the situational interest (emotional, epistemic, value-related).

4.5 METHODS AND DESIGN

The two investigations presented here were similar in structure, overall topic, objectives and evaluation design but differed in duration, learning location and complexity of the topic (for a comparison of the similarities and differences between the two studies, see Table 4.1). In each case, scientists of marine ecology, media psychology and education developed the experiments and simulations together in a co-design. The methods were based on real scientific data. The experiments were hypothesis-driven model experiments and the simulations were interactive and instructionally supported.

Table 4.1. Comparison of the two presented studies

	Study I	Study II
Location	School	Student laboratory
Topic	Ocean acidification and impacts on calcifying organisms (one-dimensional)	Warming, eutrophication, salinity and ocean acidification of the Baltic Sea and impacts on three organisms, their interactions and challenges on the ecosystem/social level (multidimensional)
Duration	90 minutes	180 minutes
Design	1. Pre-test (20 min) 2. Introduction (20 min) 3. Practical work: exp./sim. (30 min) 4. Post-test (20 min)	1. Pre-test (15 min) 2. Introduction (30 min) 3. Practical work: exp./sim. (120 min) 4. Post-test (15 min)
Participants	$N = 443$ ($N_{exp} = 221$, $N_{sim} = 222$) Grade: 10-13 Average age: 17.58 years	$N = 367$ ($N_{exp} = 198$, $N_{sim} = 169$) Grade: 10-13 Average age: 17.02 years
Instruments	Same measurements for both studies: Personal data (age, gender, marks in science subjects) Individual interest in biology & chemistry (adapted from Frey et al., 2009) Prior knowledge (self-developed instrument) Content knowledge (self-developed instrument) Cognitive load (Paas, Tuovinen et al., 2003) Situational interest (adapted from Engeln, 2004)	

We conducted both studies using a simple experimental research design (Figure 4.1) with type of learning location as between-subjects factor. Thereby the investigation of the effects of the simulation represented the experimental group (EG) and the investigation of the effects of the experiments represented the control group (CG).

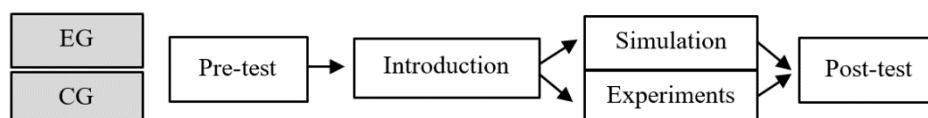


Figure 4.1. Study Design

However, when we speak of "experiment" in the following, we always mean the experiment as a learning method, which we have used in school or in the student laboratory. We used a pre-test to assess students' personal data as well as their prior knowledge, marks in science subjects and interest in biology and chemistry (independent variables). The post-test analyzed the effectiveness of simulation-based learning compared to experiment-based learning regarding content knowledge, situational interest and cognitive load (dependent variables).

4.5.1 Design of Study I

The first study was a 90-minute intervention at school. The purpose of this intervention was to convey the process and the effects of ocean acidification on a global and local level. In an initial introduction, students received general information related to the testing and the course of the day. Subsequently, a 20-minute paper-pencil-test took place. The introductory lecture provided an overview of the topic of ocean acidification and highlighted resulting problems for marine ecosystems. Afterwards, participants were randomly assigned into two groups. We separated the groups into different rooms to avoid any interference while conducting the experiment or the simulation, respectively. Students had to work on their assigned method for 30 minutes. The experiments were conducted in small groups with a supervisor who guided the experiment and was available for questions. For the simulation, each student used his own laptop, but working in small groups was allowed. A supervisor was available for technical as well as content related questions. The same supervisors were present during the entire test period. Finally, we applied a 20-minute post-test.

4.5.2 Materials of Study I

Both methods conveyed the same content: pH-value, reasons for and extent of the increase in global atmospheric carbon dioxide (CO_2) concentration, equilibrium reaction of CO_2 in seawater and the effect of acidification on calcifying organisms. In both treatments, students used the same research questions to investigate the process and effects of ocean acidification. The activities were supported by a script, in which the results of the simulation or experimental work had to be summarized by leading questions. The tasks were the same for both methods. An example of this is: *"Explain why calcification is more difficult with increased CO_2 concentration in the atmosphere. Take into account the previously established reaction equations for the equilibrium system."*

Hands-On Experiment

First, students investigated the extent of the increasing CO_2 concentration in the atmosphere and the characteristics of the pH-value in the script. This included analyzing a Keeling Curve and matching different liquids to the corresponding pH-value. Then they conducted an experiment that mainly focused on the consequences of an increased atmospheric CO_2 content for seawater with special regard on the buffering effect. An experimental setup was hence chosen that represents the ocean

(Baltic Sea water), the combustion of fossil fuels (candles), and the atmosphere (upside down aquarium). Distilled water was used as a control. In both water samples, a digital pH meter measured the changes of the pH-value. After 10 minutes of testing, the students observed a considerably faster decrease in pH-value in the distilled water than in the water of the Baltic Sea. After documenting the results, the students set up the equilibrium reaction equation of CO_2 in seawater and thus addressed the buffering effect of seawater as an explanation for the different changes of the pH-value in the two water samples. Finally, they analyzed the resulting effects on calcifying organisms such as mussels, which were present as an illustrative object. The experiment used here is part of the BIOACID-project (Biological Impacts of Ocean Acidification) and was developed by scientists researching ocean acidification as part of their public relations work (BIOACID, 2012).

Interactive Computer Simulation

The simulation is a learning environment of the Stanford University for which permission had been granted for use on this research project. As an introduction, the digital learning tool illustrated the reasons for and the extent of the increasing atmospheric CO_2 concentration by an animated Keeling Curve. Then the computer simulation offered the possibility to interactively examine the characteristics of the pH-value by matching the acidity of different liquids on a pH scale. In the main section, students were able to control the increase in atmospheric CO_2 concentration and observe the resulting effects on an animated equilibrium reaction of seawater. For this purpose, the students simulated the CO_2 concentration of the atmosphere under three different scenarios using a slider from the year 1865 to 2090. In real time they could observe changes in the schematically presented equilibrium reaction as well as changes in the exact concentrations of carbon dioxide (CO_2), hydrogen carbonate (HCO_3^-), and carbonate (CO_3^{2-}) (Figure 4.2). In the next part, the learners had to interactively differentiate between calcifying and non-calcifying organisms and subsequently investigate the negative consequences of acidification on the calcification process of the respective organisms. Supporting elements were implemented such as toolboxes which, when clicked on, explain how to read the Keeling curve or explanations that appear when swiping over various reaction arrows.

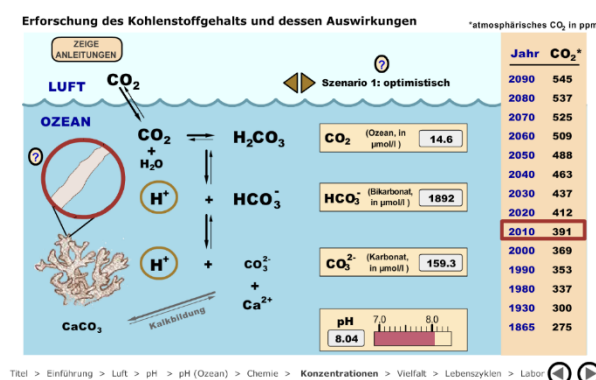


Figure 4.2. Screenshot of the simulation, Study I (<http://i2sea.stanford.edu/AcidOcean/AcidOcean.htm>)

4.5.3 Design of Study II

The second study was part of a full-day student lab day. The study presented here consisted of a 180-minute intervention for students of Grade 10 - 13 on the topic "Future of the Baltic Sea". The purpose of this intervention was to convey the processes of major environmental impacts of the Baltic Sea (warming, eutrophication, acidification and salinity changes) and its effects on representative organisms of the ecosystem (gammarids, bladderwrack, and epiphytes) as well as the resulting challenges for the whole system (water quality, fishing, tourism). The 15-minute pre-test took place after receiving general information about the testing and the course of the day. The students carried out all testing using a digital questionnaire on tablet computers. Subsequently, a 30-minute introductory lecture provided information on the causes and processes of global changes in the oceans and gave an insight into the resulting effects on marine ecosystems. Afterwards we randomly assigned the participants into two groups and separated them into different rooms. The experiment group was further divided into two subgroups, each conducting four experiments of 30 minutes in different rooms. A supervisor guided the experiment and was available for questions during the procedure for each group. The simulation group was also divided into two subgroups, each working at a group table. Although students had their own tablet, cooperation was allowed. A supervisor was available for technical as well as content related questions. The learning period consisted of two hours for all groups and was followed by the 15-minute digital post-test.

4.5.4 Materials of Study II

Both methods conveyed the same content. The experiments each conveyed a single process of change (warming, acidification, eutrophication, or salinity changes) with the effects on one organism (gammarids, bladderwrack, or epiphytes) and the resulting ecosystemic and societal changes (water quality, fishing, or tourism). In the simulation, it was possible to simulate all changes simultaneously and to observe the effects on all three organisms together, taking into account their interactions. Furthermore, the adjusted parameters represented possible effects on the entire system (water quality, fishing, and tourism). To avoid disorientation and cognitive overload especially by working on the simulation, students had to work on a supporting script in which they had to summarize the results of their work by the same guiding questions. An example of this is: *"Describe the effect of elevated water temperature on bladderwrack fitness"*.

Hands-On Experiments

The students investigated the processes and effects of (a) increased water temperature on the fitness of bladderwrack; (b) over-fertilization on the growth rate of epiphytes; (c) changed salinity on the fitness of gammarids and (d) ecosystem changes caused by increasing acidification.

Interactive Computer Simulation

The overall goal of the computer simulation was to enable learners to understand the effects of the combination of different ecosystem changes on all three organisms in interaction. Before the students could interact with the simulation, they listened to short informative audio files on each variable of the simulation for basic information. In the interactive mode, the students could then interact with the simulation in a self-determined manner. The interface allowed users to select and manipulate the different changes by moving a slider (see Figure 4.3). The students could observe shifts in the population sizes of the three organisms in real time. We also implemented supporting elements to improve learning such as toolboxes providing information about each change and the organisms.

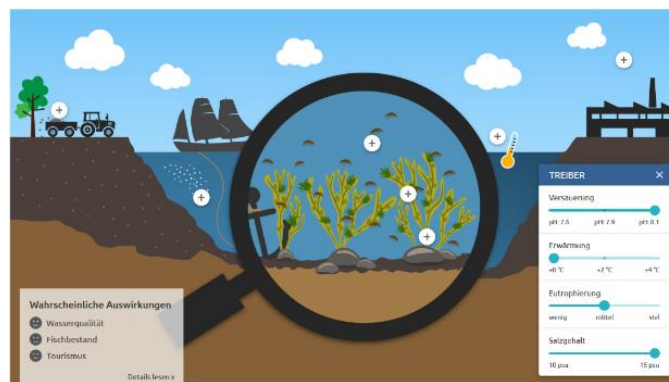


Figure 4.3. Screenshot of the simulation, Study II (<https://ostsee-der-zukunft.experience-science.de/simulation.html>)

4.5.5 Samples of Study I + II

The participants in Study I were 443 students from 19 German secondary schools with an average age of 17.58 years ($SD = 1.41$), 56.88% students were female and 43.12% students were male. The random dividing of the classes into the methods resulted in a distribution of 221 students who worked on the experiments and 222 students who worked on the simulation.

The participants in Study II were actually 367 students from 21 German schools. The average age was 17.02 years ($SD = 1.20$), 54% of the students were female and 46% were male. The experiments were conducted by 198 students and the simulation by 169 students.

4.5.6 Measures of Study I + II

In the pre-test we assessed sociodemographic data like age, gender and grade for a better impression of the sample. In addition, we asked for the students' marks in science subjects (biology, chemistry, physics) as well as prior knowledge and individual interest in biology and chemistry to better understand the pre-existing cognitive and motivational competencies of the participants. In the post-test, we applied questionnaires on content knowledge, cognitive load and situational interest.

Content Knowledge

We developed different questionnaires for pre- and post-testing to investigate content knowledge. Since the topics of both studies were not part of the German standard curriculum, we expected only little prior knowledge. Therefore, an increase in content knowledge through the interventions was highly expected. We administered only a short pre-test, to avoid frustration as well as a testing effect, i.e. a learning effect because of answering the same questions twice. The content knowledge pre-test is only about verifying possible differences in prior knowledge between the later randomly divided test groups. We developed a detailed post-test because we focused on the difference between the two methods.

In the first study, the pre-test consisted of three multiple-choice items on basic principles of ocean acidification. Two items had four different answering options and were scored with one point; one item had five different answering options and was scored with two points. Students could achieve four points in total. The post-test consisted of nine questions. The structure of the questions based on the content areas of the methods: pH-value, reasons for and extent of the increase in global atmospheric carbon dioxide (CO₂) concentration, equilibrium reaction of CO₂ in seawater and the effect of acidification on calcifying organisms. Five multiple-choice items with four different answering options were developed. There was one correct answer for each question, which was scored with one point. There were also three multiple-choice questions with five answering options and two correct answer possibilities. These items were scored with two points. In addition, we developed a task where students should mark the increase or decrease of the oceans' concentrations of carbon dioxide, hydrogen carbonate and carbonate in a table with an arrow. Three points could be achieved for this. The participants were able to score up to 15 points in total. Both tests were developed on the basis of existing knowledge tests in chemistry (Höft et al., 2019). See Table 4.2 for example items for the different content knowledge questionnaires.

The knowledge pre-test in the second study included three open-ended questions that tested the general state of knowledge about changes and challenges of the Baltic Sea ecosystem. The developed expectation horizon resulted in 18 possible points. The post-test included 15 multiple-choice questions and four open-ended questions. The assessed questions were also structured according to the methods' content: treated organisms and their interactions, processes of the changes, effects of a single change and effects of combined changes. For the last three open questions, students had to (a) describe the effects of all four predicted changes in combination for the year 2100 at the organism level and (b) the resulting impacts on the ecosystem as well as (c) on the societal level. The multiple-choice questions provided four different answer options. Each multiple-choice item was scored with one point; the open questions were scored with three points. In total, the participants could score up to 27 points. For examples of the different content knowledge tests see Table 4.2.

4. Comparison of Experiments and Simulation

Table 4.2. Example items of used questionnaires for knowledge acquisition

Scale	Example Item Study I	No. of Items	Example Item Study II	No. of Items
Prior Knowledge	What happens when CO ₂ is dissolved in seawater? a) Mainly hydrogen carbonate ions (HCO ₃ ⁻) are formed b) Mainly carbon acid (H ₂ CO ₃) is formed c) The pH-value rises d) The content of calcium carbonate ions increases	3	Describe the causes and effects of eutrophication of a water body. (open question)	3
Content knowledge	What is the current CO ₂ concentration in the atmosphere? (indicated in ppm = parts per million) a) 275 ppm b) 1005 ppm c) 885 ppm d) 408 ppm	9	Due to a lower salinity of the Baltic Sea... a) there will be more gammarids b) there will be fewer epiphytes c) there will be more bladderwrack d) there will be fewer gammarids	19

Cognitive Load

We decided to measure cognitive load considering that working on interactive computer simulations and conducting hands-on experiments demand a certain amount of learners' cognitive resources. Thus, we implemented the cognitive load test by Paas, Tuovinen et al. (2003) in the post-test phase (student self report). Therefore, students had to evaluate their perceived cognitive load within two questions on a 7-point rating scale (1 = made no effort at all; 7 = made a real effort). See Table 4.3 for an example item.

Interest

We examined interest in biology and chemistry to control differences in individual interest as an influence variable on situational interest. These two disciplines were chosen because they represent the fundamental areas of the topics addressed in both studies. For this purpose, we adapted the test "pleasure and interest in science" for general interest in science to interest in biology and chemistry. The test was originally developed and validated for the PISA study (Frey et al., 2009). The students had to assess five statements each on their individual interest in chemistry and biology using a 4-point rating scale (1 = completely disagree; 4 = completely agree).

Participants' situational interest (SI) in the simulation and experiments was assessed via the questionnaire developed and validated by Engeln (2004). The test used 12 items to measure the emotional, epistemic and value-related components of the situational interest. Participants could indicate their answers on a 4-point rating scale (1 = completely disagree; 4 = completely agree). See Table 4.3 for example items.

Verifying the Instruments' Quality

We piloted the instruments for interest and cognitive load with a group of $N = 44$ students from three different classes of Grade 13 (Table 4.3).

Table 4.3. Summary of reliabilities (Cronbach's α) of used scales in the pilot study ($N = 44$)

Scale	Cronbach's α	No. of Items	Example Item
Interest in biology	.931	5	I am interested in learning new things in biology.
Interest in chemistry	.920	5	I am interested in learning new things in chemistry.
Cognitive load	.797	2	How difficult was the simulation to understand?
Situational interest emotional	.749	4	I felt comfortable while working on the experiment/simulation.
Situational interest epistemic	.519	5	I would like to learn more about the things we worked on in the simulation/experiment.
Situational interest value-related	.392	3	It is important to me personally that we did the experiments/simulations today.

The analysis of the reliability of the value-related situational interest resulted in a Cronbach's alpha value of .510 if one of the items was not considered. We attributed the low reliability of this component to linguistic inconsistency and improved this in the following. All other scales showed sufficiently high reliabilities and could be used without modifications for the main studies. We developed both content knowledge tests in collaboration with a teacher and a marine biology scientist to ensure a high content validity. The content knowledge questionnaires were validated by the same students of the pilot study for Study 1 and by a group of different 23 students from Grade 12 for Study 2. The students conducted the interventions as planned, but answered the questions in an open plenary session with us. This collaborative validation enabled us to eliminate ambiguities in formulation and specialist terminology.

After the adjustments of the pilot studies, we could determine the following internal consistency for the instruments used in Study I and Study II (Table 4.4).

Table 4.4. Summary of reliabilities (Cronbach's α) of used scales for Study I + II

Scale	Cronbach's α	
	Study I	Study II
Interest in biology	.917	.900
Interest in chemistry	.919	.891
Cognitive load	.595	.586
Situational interest emotional	.825	.801
Situational interest epistemic	.621	.748
Situational interest value-related	.555	.763

4.7 RESULTS

All results presented here were calculated with the statistics program SPSS. We used *t*-tests to examine mean value comparisons. The *t*-test indicated no significant differences in prior knowledge, average marks in the science subjects (biology, chemistry, physics), nor in interest in biology or chemistry between the later random assignment to the groups (experiments or simulation) of both studies (Table 4.5 and Table 4.6). We checked these possible differences in the pre-test questionnaires to exclude an effect on differences of the dependent variables in the later randomly divided groups. The analysis of the prior knowledge questionnaire showed that students achieved an average of 1.3 points ($SD = 1.05$) out of possible 4 points in the first study. In the second study students achieved an average of 3.38 points ($SD = 2.46$) out of possible 18 points (Table 4.5 and Table 4.6).

Table 4.5. Means (standard deviations) of independent variables of both groups and corresponding values of the *t*-tests for Study I

Pre-test Study I	Experiments Mean (SD)	Simulation Mean (SD)	<i>df</i>	<i>t</i>	<i>p</i>
Prior knowledge	1.30 (1.04)	1.29 (1.06)	440	0.059	.95
Marks in science subjects	2.59 (0.85)	2.50 (0.83)	424	1.041	.30
Interest in biology	2.89 (0.70)	2.92 (0.74)	438	-0.434	.66
Interest in chemistry	2.25 (0.80)	2.37 (0.77)	438	-1.601	.11

Table 4.6. Means (standard deviations) of independent variables of both groups and corresponding values of the *t*-tests for Study II

Pre-test Study II	Experiments Mean (SD)	Simulation Mean (SD)	<i>df</i>	<i>t</i>	<i>p</i>
Prior knowledge	3.16 (2.44)	3.63 (2.47)	363	1.807	.07
Marks in science subjects	2.95 (1.10)	3.00 (1.04)	361	0.527	.60
Interest in biology	2.96 (0.66)	2.93 (0.64)	362	0.435	.66
Interest in chemistry	2.47 (0.67)	2.47 (0.70)	364	-0.027	.98

The *t*-tests of the dependent variables of both studies confirmed that on the one hand, learning with the simulation compared to learning with experiments resulted in higher students' content knowledge achievement ($d_{Study I} = -0.19$; $d_{Study II} = -1.05$) and a higher level of cognitive load ($d_{Study I} = 0.19$; $d_{Study II} = 0.21$). On the other hand, students how worked with the experiments showed a higher level of the epistemic ($d_{Study I} = -0.33$; $d_{Study II} = -0.54$) and value-related ($d_{Study I} = -0.35$; $d_{Study II} = -0.37$) component of the situational interest by than by working with the simulation. We could not observe a difference in the emotional component of situational interest between the two methods for both studies. All means, standard deviations and statistic values are shown in Table 4.7 and Table 4.8 and presented in Figure 4.4 - Figure 4.7.

Table 4.7. Means (standard deviations) of dependent variables and corresponding values of the t -tests and effect sizes (Cohen's d) for Study I

Post-test Study I	Experiments Mean (SD)	Simulation Mean (SD)	df	t	p	d
Content knowledge	7.90 (3.06)	8.51 (3.09)	441	-2.08	.038	-0.19
Cognitive load	2.96 (0.97)	3.17 (1.08)	441	2.15	.032	0.19
Situational interest emotional	3.04 (0.83)	3.07 (0.64)	441	0.34	.735	-
Situational interest epistemic	2.38 (0.57)	2.19 (0.56)	441	-3.43	.001	-0.33
Situational interest value-related	2.7 (0.57)	2.49 (0.59)	438	-3.68	< .001	-0.35

Table 4.8. Means (standard deviations) of dependent variables and corresponding values of the t -tests and effect sizes (Cohen's d) for Study II

Post-test Study II	Experiments Mean (SD)	Simulation Mean (SD)	df	t	p	d
Content knowledge	8.58 (3.81)	13.33 (4.49)	365	-10.95	< .001	-1.05
Cognitive load	2.75 (0.95)	2.99 (1.04)	365	2.28	.023	0.21
Situational interest emotional	2.41 (0.62)	2.33 (0.57)	364	1.28	.203	-
Situational interest epistemic	3.22 (0.55)	2.9 (0.61)	365	-5.18	< .001	-0.54
Situational interest value-related	2.85 (0.67)	2.62 (0.59)	364	-3.5	.001	-0.37

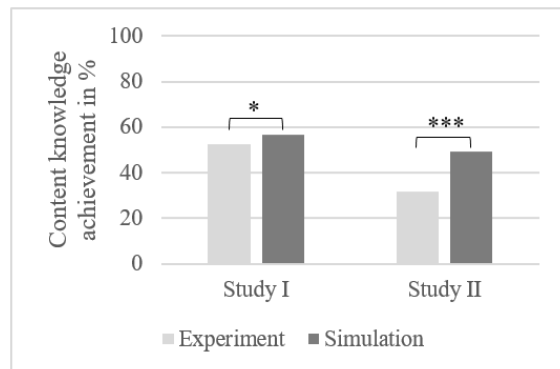


Figure 4.4. Differences in content knowledge achievement in % between the methods for both studies (Study I: Intervention at school $N_{Exp} = 221$, $N_{Sim} = 222$; Study II: out-of-school intervention $N_{Exp} = 198$, $N_{Sim} = 169$)

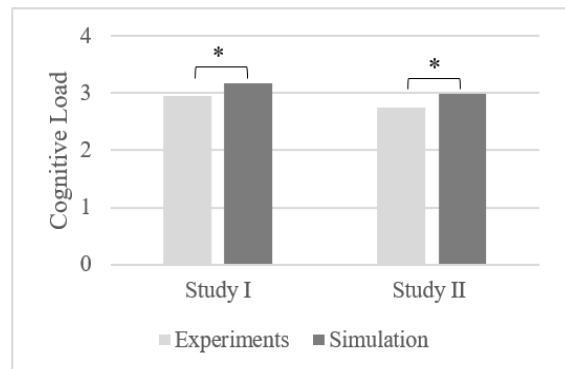


Figure 4.5. Differences in mean cognitive load between the methods of both studies (Study I: Intervention at school $N_{Exp} = 221$, $N_{Sim} = 222$; Study II: out-of-school intervention $N_{Exp} = 198$, $N_{Sim} = 169$)

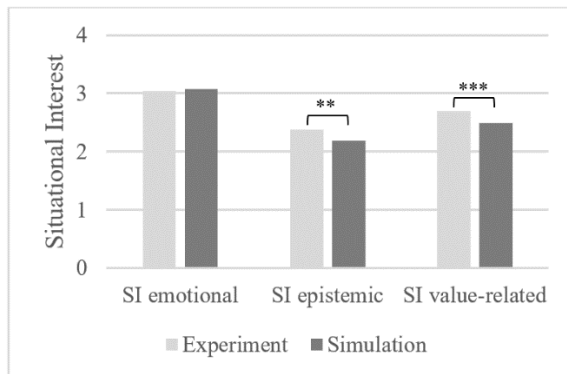


Figure 4.6. Differences in mean situational interest (SI) between the methods of Study I ($N_{Exp} = 221$, $N_{Sim} = 222$), subdivided into different components

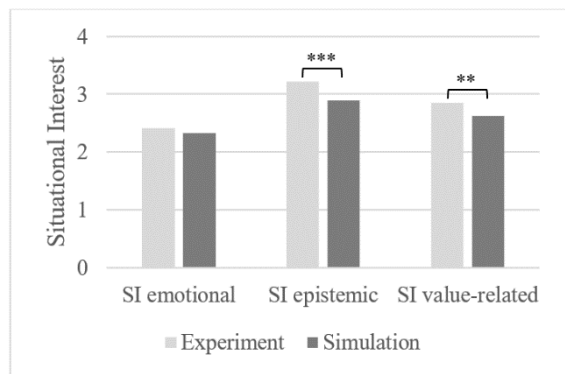


Figure 4.7. Differences in mean situational interest (SI) between the methods of Study II ($N_{Exp} = 198$, $N_{Sim} = 169$), subdivided into different components

4.8 DISCUSSION

The goal of this research was to investigate the differences between learning with computer simulations and experiments concerning a) the contribution of content knowledge, b) the extent of affected cognitive load, and c) the extent of situational interest to find out which method is better suited to communicate current and complex topics. Therefore, we conducted two studies using a simple experimental research design with type of learning location as between-subjects factor. The following sections show detailed explanations of the assumptions for each research question and resulting implications.

4.8.1 Content Knowledge

The low achievements in the pre-test indicate that the prior knowledge was very low in both studies, as expected. This is probably because the topics did not belong to the standard German curriculum. The expectedly non-significant differences of prior knowledge as well as marks in science subjects between the two randomly assigned treatment groups suggest that the results for the differences in content knowledge achievement cannot be attributed to differences in prior knowledge or school success in science subjects.

In contrast to frequently shown results (Jong, 2010; Jong & van Joolingen, 1998; Köck, 2018) the students showed great learning success when working with simulations, despite increased cognitive load. This contradicts our assumptions of the first research question. Part of the explanation could be the appropriate instructional support in each simulation. Results from research literature show that especially for students with little prior knowledge – such as those in our studies – instructional support offers effective assistance for successful knowledge acquisition (Eckhardt et al., 2018; Jong & van Joolingen, 1998; Mayer, 2004; Rutten et al., 2012). We claim that these assumptions about the importance of instructional support should be considered since increasing digitalization is currently creating more and more digital and interactive learning environments.

The topics dealt with in our studies both conveyed not only rudimentary content but also complex processes and structures especially in the second study. The great effect of the learning advantage of simulations compared to the experiments in the second study ($d = 1,05$) indicates that interactive computer simulations are particularly suitable for teaching complex processes and systems, as already assumed by other authors (Smetana & Bell, 2012). Scheuring and Roth (2017) and Lichti and Roth (2018), respectively, were able to show that computer simulations primarily promote complex thinking processes.

We also note that the high level of interactivity and the possibility of self-determined action within the simulation are, as already shown, of great importance for learning challenging content (Linn et al., 2010). However, since learning which is solely oriented towards self-determined learning of scientific principles and concepts often leads to less effective learning success (Jong & van

Joolingen, 1998; Mayer, 2004), the students in our studies worked in groups or with a partner. This might have helped to bypass the low level of knowledge acquisition often found in exploratory learning studies using computer simulations (Jong, 2010).

4.8.2 Cognitive Load

The expected higher cognitive load when working with computer simulations can be explained as follows: The students could change several variables at the same time (Study I: CO₂ concentration + scenarios; Study II: warming + acidification + eutrophication + salinity) and had to observe their effects on several aspects (Study I: equilibrium reaction + calcification process of the coral; Study II: bladderwrack + amphipods + epiphytes + their interactions). This non-linear structure of model-based simulations resulted in higher complexity of the learning method. As already stated several times this is attributed to a high level of cognitive load (de Jong, 2010; Stull & Hegarty, 2016).

4.8.3 Situational Interest

Since no difference was found between the two treatment groups in interest in biology and chemistry, this may indicate that the observed differences in situational interest between the groups are not due to differences in individual interest.

As shown in Section 4.3.3, situational interest does not depend on the individual preference for a certain object but rather on the interest of the object in a concrete situation. The subdivision of the interest into emotional, value-related and epistemic components allows a more detailed analysis of the students' perceived interest. The learners associated working with both methods with positive feelings and emotions (emotional component). The higher situational interest on epistemic and value-related level while working on experiments compared to computer simulations contradicts the hypothesis of our third research question. The literature, which emphasizes the interest-promoting and motivating character of computer simulations, largely originates from a pre-digital era in science education (Jain & Getis, 2003; Rutten et al., 2012). Today's students grow up with digital media (so-called digital natives) and are not easily impressed by a "novelty" effect, the interactivity, the possibility of self-determined interaction within the simulation, or the digital medium itself. This will probably have an impact on the value-related component in particular. Nowadays, working with a digital medium itself no longer has any special value for the learners because they are used to it. This leads to the question of whether the existing assumptions are still valid or need to be reassessed considering the digital transformation of society. Consequently, the often-shown interest-enhancing effect of computer-based (learning) environments might be outdated – while hands-on learning experiences might have a greater motivational and interest-enhancing impact than expected (especially with regard to the value-related and epistemic components).

Experiments, on the other hand, represent something not commonplace. In everyday school life teachers often lack time, equipment and opportunities to let students conduct experiments independently. Therefore, practical work might be special and peak their situational interest. This conforms to the research of Lin et al. (2013) who indicated a positive influence of activities that are novel or conspicuous on students' situational interest. These attributes could have led in particular to the students' desire to learn more about the topics they dealt with through working with the methods (epistemic component).

4.8.4 Limitations

The low reliability we found for the instrument for cognitive load (Table 4.4) raises some doubts about the value of our results. However, we have used this method because it has been shown that this subjective evaluation scale is the most sensitive measure available to differentiate the cognitive load of different teaching methods (Sweller, 2011). Furthermore, Naismith and Cavalcanti (2015) stated in a review that the validity of self-report instruments does not differ from other instruments such as secondary task methods or instruments with physiological index. To improve the rigor of measuring cognitive load in future the usage of a more sophisticated measurement like dual-task measurement (Brünken, Plass, & Leutner, 2004) or psychometric scales that distinguish between categories of cognitive load (Leppink, Paas, van Gog, van der Vleuten, & van Merriënboer, 2014) might be preferable.

4.8.5 Conclusion

This paper provides current insights into some students' motivational and cognitive effects while working on experiments and computer simulations. We could show repeatedly the advantages of interactive computer simulations with regard to the communication of complex contents as well as the importance of hands-on learning situations to promote students' situational interest (especially with regard to the value-related and epistemic components). We assume that the results are independent of the learning location, because the investigations in both studies showed the same results. Furthermore, the high number of test persons ($N_{\text{total}} = 810$ students) makes this paper particularly meaningful. The assumptions offer educators indications for their choice of an appropriate method for communicating complex socio-scientific issues for school and out-of-school education.

We pointed out that promoting interest is just as important for science education as teaching content knowledge. As this study has no clear result regarding the suitability of one of the two methods examined here to fulfil these two targets, we cannot give a clear indication of the preferred use of one of the methods in science education. Rather, a combined approach of both methods seems to be the right way to benefit most from the positive effects we could observe. Smetana and Bell (2012) as well as Lichti and Roth (2018) also pointed out the combination of laboratory experiments and model-based simulations as a potentially powerful learning tool. In addition, de Jong, Linn, and

Zacharia (2013) emphasize a combination of virtual and non-virtual learning elements seems to enable a deeper and more nuanced understanding, especially when teaching complex issues. We conclude by stating that motivational and cognitive effects of such a combination should be investigated in future research.

5 A COMBINATION OF HANDS-ON EXPERIMENTS AND INTERACTIVE COMPUTER SIMULATION AS LEARNING TOOLS IN OUT-OF-SCHOOL SCIENCE EDUCATION

5.1 ABSTRACT

One of the main objectives of science education is to enable students to actively participate and engage in socioscientific issues (SSI). Current SSI are complex and difficult to communicate using one established method alone: Hands-on experiments often simplify the real complexity to focus on one aspect, computer simulations on the other hand can cause high cognitive load due to the complexity of interactions. This study investigates educational effects of a combination of these two methods as learning tools in out-of-school science education focusing on content knowledge, cognitive load and situational interest. Therefore, we (1) investigated effects of these two methods individually, (2) investigated effects of a combined approach, and (3) analyzed effects of the order of methods. Results of the empirical study ($N = 367$) indicated that a simulation conveyed content knowledge better, experiments provided more situational interest. Two methods are better than one for teaching content knowledge but not necessary in terms of situational interest or cognitive load. Results implicated that experiments have a complementary suitability for simulations in terms of conveying basic knowledge. We recommend a combination of first experiments and second simulation, to obtain the best advantages in achieving a comprehensive understanding and the necessary interest for active participation and engagement in societal discussions about SSI. The findings implicate that a combination of both methods might be a successful learning tool in science education, as it seems to be particularly useful for communicating current complex scientific topics to students.

5.2 INTRODUCTION

In today's society, many complex changes on an environmental, economic or societal level and resulting new challenges affect the educational process. So-called socioscientific issues (SSI) are complex, ill-structured problems at the interfaces between science and other aspects of society. They are based on scientific concepts, are subject to several, sometimes contradictory perspectives and tend to be controversial and multifaceted (Herman et al., 2018; Zeidler, 2014). For example, Climate Change is defined as one of the most important issues of our time (United Nations, 2020a; World Economic Forum, 2020).

“We children are doing this to wake the adults up. We children are doing this for you to put your differences aside and start acting as you would in a crisis. We children are doing this because we want our hopes and dreams back.” This quote in particular from the Swedish climate activist Greta Thunberg from 2019, representing the entire Fridays for Future movement, shows how important and up-to-date an active participation of the young generation in societal issues is. This highlights one of the main objectives of education: the development of appropriate knowledge and competences to enable young people for an active participation in the social, political, environmental and economic life of the various social structures that affect learners' lives (Kultusministerkonferenz, 2017; UNESCO, 2016).

How is it possible to achieve such an engagement for complex topics with societal relevance like Climate Change? Students must understand the anthropogenic influence on the environment and the resulting changes for ecosystems and society. It is important to provide knowledge about the complex processes and correlations of climate change at both global and local levels. As there are many different studies that confirm the positive correlation between interest and knowledge in a specific field (Höft et al., 2019; Krapp & Prenzel, 2011; Potvin & Hasni, 2014; Schiefele et al., 1992) it is also important to have a high level of interest in the topic. According to Stoll et al. (2017) interest and knowledge provide the basis for a meaningful engagement with issues of societal relevance and for an academic career after school graduation. Additionally at least since TIMSS and PISA, there have been increasing demands to optimize the design and didactic orientation of science lessons. The aim is to promote an interest in science and the development of a deeper understanding through practice and problem orientation as well as emphasis on mental models (Prenzel, Rost, Senkbeil, Häußler, & Klopp, 2001).

In order to meet these goals of achieving students' engagement in socioscientific issues in school and out-of-school science education, educators are faced with the important decision which methods to apply. A popular learning method to which such potential is attributed is the hands-on experiment, carried out by students themselves. Experimental learning to promote inquiry skills is of great importance in the education of students (NRC, 2012; NSTA, 2013). Through the manipulation of real objects, hands-on experiments convey abstract knowledge in a more concrete and clear way, thereby improving students' academic achievement and understanding of scientific concepts (Ekwueme et al., 2015; Hofstein & Lunetta, 2004). In particular, basic processes and concepts can be vividly conveyed with hands-on experiments (Köck, 2018; Mönter & Hof, 2012). Hattie (2012) found a medium effect for learning with experiments ($d = .42$). In many cases, experiments represent replicas and simplifications of past processes of knowledge acquisition, and they often do not adequately reflect current questions and complex investigations (Braund & Reiss, 2006).

The teaching of complex systems is of great importance in the current science education policy in various countries (NSTA, 2013). In their systematic review about modern K–12 science education, Yoon, Goh, and Park (2017) also call for more research on learning about complex systems. Thus, the question of hands-on experiments' suitability for communicating complex current research topics arises – and leads to the assumption that experiments may no longer adequately represent such content in modern science education. So would it not be better to use a different learning method for communicating complex current issues?

Computer simulations, for example, are not only very important for knowledge acquisition in science (e.g. Green, Klomp, & Rimmington, 2020), they have also become an increasingly important element of science teaching, especially in subjects such as chemistry, biology, or physics (Blake & Scanlon, 2007; Rutten et al., 2012). Due to the digitalization of society, digital structures will be found in every area of work and life in the future. In this context, digital learning methods like computer simulations are not only of great importance for fostering media competence but also offer a highly sophisticated tool with many advantages for learning and teaching of science (Blake & Scanlon, 2007; D'Angelo et al., 2014; Lindgren, Tscholl, Wang, & Johnson, 2016). Students can explore the modeled system interactively by changing parameters according to their own ideas and subsequently receive direct feedback from the system about the results of their actions (Develaki, 2017; Lin et al., 2015). Computer simulations can represent natural and complex systems or processes with all their determining parameters and thus enable learners to safely experiment and simulate in an artificial learning environment (Lin et al., 2015). Empirical studies indicate that they are an effective tool particularly in communicating complex systems (Rieß, 2013; Rutten et al., 2012; Smetana & Bell, 2012) and may allow learners to develop adequate mental models of complex processes and systems (Jong & van Joolingen, 1998; Park, 2019; Sarabando et al., 2016; Siahaan et al., 2017). Srisawasdi and Kroothkeaw (2014) stated that computer-based simulations support a more meaningful learning of science concepts through the process of conceptual change. Furthermore, interactive computer simulations are considered to be of great importance in terms of increasing the motivation and interest of students (Jain & Getis, 2003; Rutten et al., 2012; Winn, 2002). Nevertheless, computer simulations often lead to a high cognitive load (Paas, Renkl et al., 2003) which evidently has a negative effect on learning success (Jong, 2010; Jong & van Joolingen, 1998; Mayer et al., 2005). The meta-study of Hattie (2012) showed only medium effects regarding the influence of simulations and simulation games on learning success ($d = .33$). The lack of interactivity in particular can lead to students learning only rudimentary content (Linn et al., 2010).

In summary, hands-on experiments convey basic concepts and processes in particular but are perhaps less suitable for presenting current socioscientific issues, due to their complexity of interacting variables. Interactive computer-based simulations, on the other hand, have proven to provide a mo-

tivating effect and to promote students' interest. They might be particularly suitable for communicating complex issues, but due to a high level of cognitive load, computer simulations often do not generate the expected learning success. The various (educational) advantages and disadvantages of hands-on experiments and computer simulations presented here question the suitability of both singular methods for the communication of complex learning contents. This leads to the overarching research question that guides this paper: Is a combination of experiments and computer simulations the preferred way to maximal benefit regarding the methods' different motivational and cognitive effects for communicating current SSI?

A combination of both methods would also be supported by the argument of positive effects of authentic science education on the learning success and interest of students (Engeln, 2004; Pawek, 2009; Woods-McConney et al., 2013). Authentic science education includes working with equipment and instruments that are as similar as possible to research, as well as experiments that are generally inquiry-based and reflect current research questions (Pawek, 2009). The experiments should be research-based and accompanied by an expert (Lee & Butler, 2003; Pawek, 2009). In science research, a combination of experiments and simulations is indispensable for the acquisition of knowledge (Graiff et al., 2020; Neumann, 2010b). The combined use of experiments and simulations in science education therefore appears to make sense not only at the motivational and cognitive level, but also as a method for authentic communication of current science research.

Some approaches combining digital and analogue learning tools already exist. For example, Smetana and Bell (2012) as well as Lichti and Roth (2018) pointed out the combination of laboratory experiments and model-based simulations as a potentially powerful learning tool. Especially when teaching complex issues, a combination of virtual and non-virtual learning elements seems to enable a deeper, more nuanced understanding (Jong et al., 2013; Winberg & Berg, 2007). Some research on system thinking follows these indications. For example, in teaching the topic of soil erosion, a higher level of system thinking competence has been shown by combining analogue and digital models than when only learning with computer simulations (Brockmüller, 2019). Studies on the topic of "forest management" showed as a central result that the combination of "classic" school science lessons focused on system thinking and a computer-simulated forest game leads to a significant increase in system thinking skills in contrast to the single use of the two components (Riess & Mischo, 2009). However, due to the different durations of the interventions in this study (two or eleven teaching hours), comparability is only possible to a very limited extent. Edsall and Wentz (2007) also conclude in their study that the combination of an analogue and a digital method should probably be the best solution, but mention the additional expense of such a combined approach (time as well as competence, capability, or technology constraints).

Assuming that combinations of both methods could foster learning, the question of the order arises, both with regard to the students' motivational and cognitive processes. Only some studies offer starting-points for these considerations. Winberg and Berg (2007), for example, examined the effect of simulations as preparation for working in the laboratory. Here an initial phase of working with a simulation stimulated students to ask more theoretical questions during the subsequent laboratory work and students achieved a greater degree of complex and correct chemical knowledge in interviews. However, the opposite order was not tested here. Furthermore, Hancock and Rummerfield (2020) observed that students who participated in a practical activity prior to a computer simulation showed better achievement on average than those who only worked on a computer simulation.

In summary, enabling students to actively participate and engage in socioscientific issues requires not only knowledge about the topic but also sufficient interest in it. With the aim of imparting competencies and interest in the topic to the students, educational advantages and disadvantages of the frequently used methods of hands-on experiments and computer simulations were identified. The use of a combined learning approach consisting of experiments and computer simulations might be a possible solution both to meet the requirements of a future digital society and with the goal of authentic science education. Effects of such a combination with regard to students' motivational and cognitive processes and effects of the order of methods have not yet been sufficiently investigated.

5.3 FOCUS OF THE STUDY

The study presented here was part of the Leibniz ScienceCampus Kiel Science Outreach Campus (KiSOC). The aim of the KiSOC is to investigate success factors for an understandable and motivating communication of the meaning and results of current science research. An essential aspect of a Leibniz ScienceCampus is the close cooperation between Leibniz institutions and universities, which gives this project the special character of an interdisciplinary collaboration between marine ecological research, research in chemistry education and media psychology. Accordingly, the development of the student laboratory day was research-based and in close collaboration with scientists, educators, and psychologists. Didactic and media-psychological research aspects were combined here to gain a deeper understanding of the motivational and learning effects of the methods and their combination.

The first goal of this study was to show differences between the two methods concerning content knowledge, cognitive load, and situational interest. The second goal was to show the effects of a combined use of experiments and computer simulations compared to a single use, and the third goal of this investigation was to compare effects of the different order of methods in a combined approach.

To investigate these research questions, we applied a specifically developed student laboratory day, "Future of the Baltic Sea", for secondary school students (Grades 10 – 13). Students investigated anthropogenic changes in the Baltic Sea, their effects on the ecosystem as well as on society and developed options for a sustainable and more positive treatment of the ecosystem. We carried out this intervention in the multidisciplinary student laboratory Kieler Forschungswerkstatt (student laboratory of the Leibniz Institute for Science and Mathematics Education (IPN) and the Kiel University), since the development and implementation of such a combined approach requires strong expertise in various fields. Compared to classroom learning opportunities, student laboratories offer a complementary potential for a more extensive and in-depth work on current topics with authentic methods (Engeln & Euler, 2004; Guderian et al., 2006). We used an experimental research design with a pre-, intermediate and post-test phase (Figure 5.1).

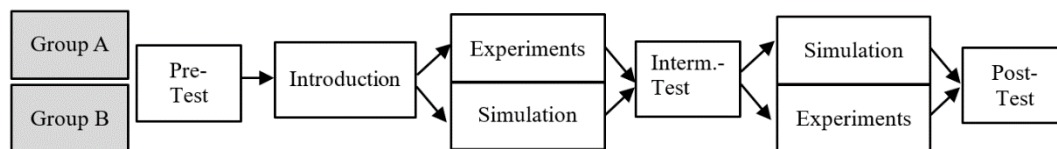


Figure 5.1. Study design

5.3.1 Research Questions

The following research questions (RQ) and corresponding hypotheses guided this project:

RQ 1: Comparison of hands-on experiments and computer simulation:

Which of the two methods will

- better convey the underlying processes and concepts;
- have a stronger influence on the cognitive load during the tasks;
- increase the students' situational interest more?

RQ 2: Comparison of combined approach and single use of methods:

In which way is a combination of methods better suited compared to single use of methods to

- contribute to an understanding of the underlying processes and concepts;
- minimize cognitive load during the tasks;
- increase situational interest of the students?

RQ 3: Comparison of the different order of methods:

What order of methods (1st Experiments + 2nd Simulation or 1st Simulation + 2nd Experiments) is preferable to:

- convey the underlying processes and concepts;
- minimize cognitive load;
- increase situational interest?

5.3.2 Hypotheses

- 1) Comparison of hands-on experiments and computer simulation:
 - a. In general, we expected negative effects of higher cognitive load for the simulation and resulting less content knowledge gain compared to the experiments (see Section 5.2). More specifically, we expected that experiments probably would better convey declarative knowledge on single parameters than the simulation, while the simulation would better convey interactions. These assumptions are supported by both research on simulations (Smetana & Bell, 2012) and experiments (Köck, 2018; Mönter & Hof, 2012) in science education. In addition, we expected low prior knowledge as the topics were not part of the German standard curriculum.
 - b. In terms of cognitive load, we expected a higher level of students' cognitive load by working on the simulation than by working on the experiments, as the level of complexity is higher (see Section 5.2).
 - c. We expected at least a medium level of situational interest for both learning environments, as the learning environment itself should have a positive influence, while working on experiments as well as simulations might be somewhat unfamiliar. We could not propose a definite hypothesis with regard to which of the two methods promotes situational interest more than the other. On the one hand, it could be expected that computer simulations promote interest more strongly, due to their novelty character, their modern appearance, and their motivational effect through the medium itself. On the other hand, the experiments offer a high degree of immersion, which should stimulate students' engagement and participation (see Section 5.2).
- 2) Comparison of combined approach and single use of methods:
 - a. We expected higher students' achievement for the overall knowledge by the combined approaches compared to the use of a single method. This is probably due to the time-on-task as well as the complementary learning advantages of the two methods.
 - b. We expected a lower cognitive load of the students in comparison to the use of a single method, since repeated working on the same content might reduce the extraneous load.
 - c. We expected a higher situational interest using the combination of methods compared to the use of a single method, as the students have more time to understand the importance of the intervention and the different methods might address different types of interests.
- 3) Comparison of different orders of methods:
 - a. We expected more content knowledge gain by working first on experiments and second on the simulation (Group A) compared to the opposite order of methods (Group B). This way, the students should be able to first learn the single process and could then better observe and understand the findings on a systematic level. Concerning the different levels of complexity, we did not have specific hypotheses.

- b. Since processing the simulation probably causes a higher cognitive load than processing the experiments, the students in Group B should start the second work phase with a higher load than in Group A. The limited cognitive resources available to the students might therefore already be heavily loaded, which should directly lead to a higher cognitive load in the second work phase. We therefore expected a higher cognitive load in Group B than in Group A.
- c. We assumed no effect due to the order of methods concerning the level of situational interest.

5.4 METHODS

5.4.1 Description of the Student Lab Day

The main intention of this student lab day was to convey processes and correlations of the main environmental impacts of the Baltic Sea (warming, eutrophication, acidification and salinity changes) and their effects on representative organisms of the ecosystem (amphipods, bladderwrack, and epiphytes). Another objective was to convey and discuss resulting challenges on the ecosystem as well as on the societal level (water quality, fishing, tourism). A 15-minute pre-test took place after receiving general information about the testing and the course of the day. The students carried out all tests using a digital questionnaire on tablet computers. In a 30-minute introductory lecture, participants received information on the causes and processes of global changes in the oceans and gained insights into resulting effects for marine ecosystems. Afterwards, we randomly assigned the participants into two groups and separated them into different rooms. The experiment group was further divided into two subgroups, each conducting four experiments of 30 minutes each in different rooms. A supervisor guided the experiment and was available for questions during the procedure for each group. The simulation group was also divided into two subgroups, each working at a group table. Although each student had his/her own tablet, cooperation was allowed. A supervisor was also available for technical as well as content related questions. The learning period consisted of two hours for all groups and was followed by a 15-minute digital intermediate-test. After a lunch break the two groups worked on the respective other method for another 120 minutes. Then the participants answered the digital post-test. A schematic overview is shown in Figure 5.1.

5.4.2 Materials of the Student Lab Day

We developed the materials of this intervention in a cooperation of scientists of marine ecology, media psychology, and education. In order to provide an authentic insight into science, hands-on experiments and the computer simulation were based on real scientific data. Additionally, we used mostly actual scientific research methods and equipment. Both methods conveyed the same content. As an inherent trait of this method, the experiments each conveyed a single process of change

(warming, acidification, eutrophication, or salinity change) with the effects on only one organism (amphipods, bladderwrack, or epiphytes) and the resulting systemic change (water quality, fisheries, or tourism) at a time. In contrast, in the simulation, it was possible to simulate all changes simultaneously and to observe the effects on all three organisms together as well as their interactions and possible systemic effects. Students had to work on an accompanying script to secure the acquired findings during the work phases. The scripts differed in their structure between the two methods: For the experiments students first had to study a theoretical introduction to the organism and corresponding change. The analogue script was then divided into the sections *research question*, *experimental design*, *results*, and *implications*. For the implications, students needed to discuss both the effects on the systemic level and the connections with the other changes. The digital script for the simulation contained the same content but was not structured by research factor but by complexity level. Thus, the students first studied the background knowledge of each change and each organism. Then they examined each change individually and afterwards the changes in combination. Finally, the effects on systemic level were examined. There they had to summarize the results of their work with computer simulation and experiments using the same guiding questions. An example of this is: *"Describe the effect of an increased water temperature on the fitness of bladderwrack"*.

Hands-on Experiments

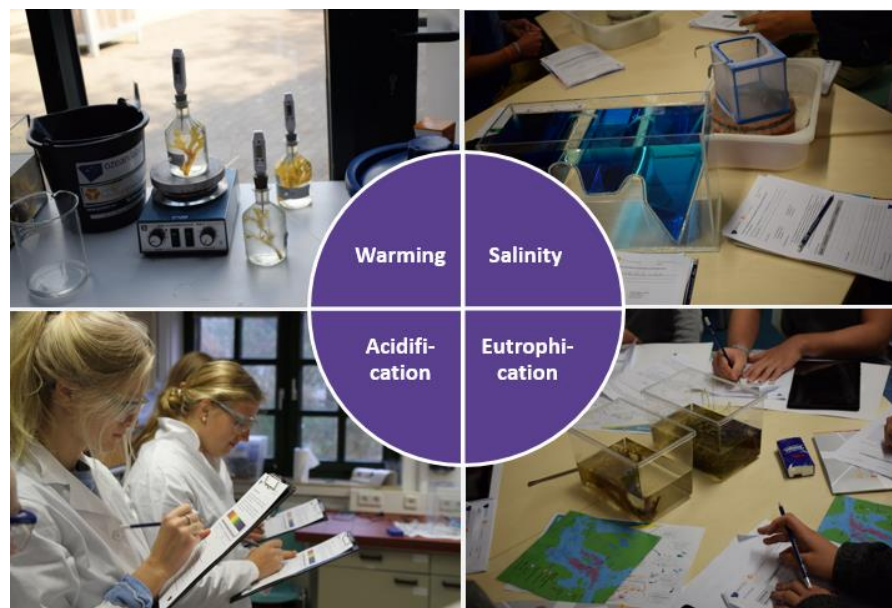


Figure 5.2. Schematic impressions of the experiments

The students investigated the processes and effects of (a) increased water temperature on the fitness of bladderwrack; (b) over-fertilization on the growth rate of epiphytes; (c) changed salinity on the fitness of amphipods and (d) ecosystem changes caused by increasing acidification (Figure 5.2).

Each experimental unit started with a problematization in which the participants learned about the effects of the single change in the Baltic Sea using real scientific data (e.g. current maps of the

oxygen minimum zones in the Baltic Sea). Then the students dealt with the real organisms and examined the effects in detail through a hands-on experiment. Afterwards they made conclusions regarding the development of the organisms' overall population. In the end, the group discussed the resulting systemic impacts at the ecosystemic and societal level. All findings had to be documented in the script.

Computer Simulation

With the help of the computer simulation, students investigated the effects of the four different ecosystemic changes on all three organisms in interaction. First, the students had to listen to short informative audio files on each variable of the simulation before they could interact with the simulation. This ensured a basic and equal information level of all participants. Afterwards the interactive mode was activated. The interface allowed users to select and manipulate the various changes by moving a slider (Figure 5.3). The students were able to observe shifts in the population sizes of the three organisms in real time as a result of their adjusted changes. We implemented supporting elements to improve learning, such as toolboxes with information about each change and the organisms to support learning with the multidimensional structure of the simulation. The students were also guided by the script and had to solve different tasks one after the other. In this way, they explored the different interactions and connections of the different changes and organisms alongside increasing complexity. Afterwards, the students discussed the effects on the systemic level in the group.

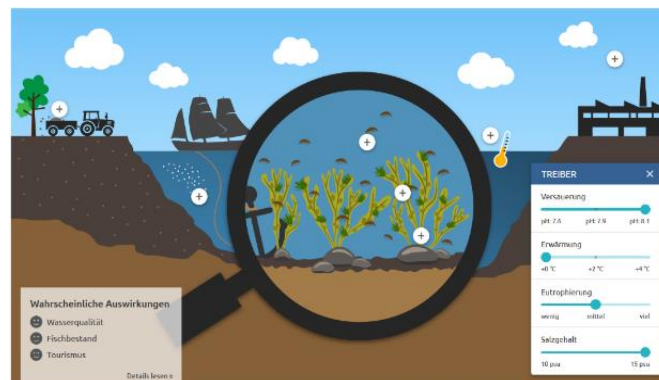


Figure 5.3. Screenshot of the computer simulation (<https://ostsee-der-zukunft.experience-science.de/simulation.html>)

5.4.3 Participants of the Study

The participants were 367 students from 21 German secondary schools. The average age of the students was 17.02 years ($SD = 1.20$) with 54% female students and 46% male students. The random division of the students into the two groups (order of methods) resulted in the following distribution: Group A (1st experiments + 2nd simulation) 198 students; Group B (1st simulation + 2nd experiments) 169 students.

5.4.4 Instruments of the Study

In the pre-test phase, we assessed sociodemographic data like age, gender, grades in science subjects (biology, chemistry, physics) as well as prior knowledge and interest in biology and chemistry. In the post- and intermediate-test phase, we asked for content knowledge, cognitive load and situational interest.

Content Knowledge

We developed a prior knowledge test to get an impression of students' – supposedly low – level of knowledge in order to verify possible differences between the later randomly divided test groups. The knowledge pre-test consisted of three open questions testing the participants' general level of knowledge about changes and challenges of the Baltic Sea ecosystem. For the intermediate- and post-test we developed 15 multiple-choice questions and four open-ended questions. The questions were structured according to different levels of complexity: declarative knowledge (DK), basic interactions (BI), and complex interactions (CI) (see Table 5.1 for an overview).

Table 5.1. Used scales for knowledge acquisition

Scale	No. of Items	Answer option	Example Item
Prior Knowledge	3	open questions	Describe the causes and effects of eutrophication of a water body.
Declarative Knowledge (DK)	8	multiple choice	Which of the following attributes are characteristic for bladderwrack? (a) The grass-like algae grows mainly on sandy ground. (b) The bladderwrack is a seaweed genus of the red algae. (c) Gas bubbles give the kelp buoyancy in the water. (d) The bladderwrack grows on other plants to get a better supply of light. (e) I don't know.
Basic Interactions (BI)	5	open questions (1) multiple choice (4)	Due to a lower salinity of the Baltic Sea... (a) there will be more amphipods (b) there will be fewer epiphytes (c) there will be more bladderwrack (d) there will be fewer amphipods
Complex Interactions (CI)	7	open questions (4) multiple choice (3)	What causes a particularly strong decrease in the amphipod population? (a) acidification + eutrophication (b) warming + lower salinity (c) warming + acidification (d) eutrophication + lower salt concentration (e) I don't know

The multiple-choice questions provided four different answer options and the option “*I don't know*” to prevent guessing. Each multiple-choice item was scored with one point; the open questions were scored with three points. In total, participants could score up to 27 points.

In the post-test, we also asked the students for their opinion on the more effective sequence of the method with the following question: “*In your opinion, which order of methods has best enabled the*

understanding of the processes of the future Baltic Sea?” Therefore the students had to choose one of the answer options “*Order A*”, “*Order B*” or “*I don’t care*”.

Cognitive Load

According to the Cognitive Load Theory, successful learning can only occur if the (limited) cognitive abilities of learners in the working memory system are not overloaded (see van Merriënboer and Sweller (2005) or Sweller (2011) for an overview). The theory states that there are three types of cognitive load. Learners have to deal with a certain intrinsic cognitive load, which refers to the difficulty and complexity of the task, and with extraneous cognitive load, which is generated by suboptimal instructional design, i.e., the difficulty in dealing with the way material is presented. Lastly, germane cognitive load as “effective cognitive load” (Sweller, 2005, p. 27) is caused by effective learning and should result in the processing and construction of schemas in the long-term memory. All three loads add up and result in an overall cognitive load. Cognitive overload is especially likely to occur in cases of very difficult tasks (high intrinsic cognitive load) combined with inappropriate and overly complex instructional designs (high extraneous cognitive load). This often results in a low learning success of the students (Mayer et al., 2005).

Considering that working on interactive computer simulations and conducting hands-on experiments demand a certain amount of learners’ cognitive resources, we decided to measure cognitive load. Thus, we implemented the cognitive load test by Paas, Tuovinen et al. (2003) in the intermediate- and post-test phase. In a self-report, students had to evaluate their perceived cognitive load within two questions on a 7-point rating scale (1 = made no effort at all; 7 = made a real effort).

Interest

It is essential to investigate the level of interest generated by the methods, considering many different studies that confirm the positive correlation between interest and knowledge in a specific field (Krapp & Prenzel, 2011; Potvin & Hasni, 2014; Schiefele et al., 1992). Interest is described as content specific (i.e., specific to an object, domain, or activity) and has a multicomponent structure (including cognitive and affective components) (Krapp & Prenzel, 2011; Renninger & Hidi, 2011). Two types of interest can be differentiated in educational research: individual and situational interest. Individual interest is a relatively permanent predisposition attending objects, events or ideas and deals with certain contents (Renninger, 2000; Schiefele, 1998). Situational interest is mainly caused by situation-specific environmental stimulations (Knogler, Harackiewicz, Gegenfurtner, & Lewalter, 2015) like activities that are novel or conspicuous (Lin et al., 2013; Palmer, 2009).

We examined interest in biology and chemistry to control differences in individual interest as an influence variable on situational interest. These two disciplines (biology and chemistry) were chosen because they represent the fundamental areas of the topics addressed in this intervention. Therefore, we adapted the test “pleasure and interest in science” to interest in biology and chemistry. The

test was originally developed and validated for the PISA study (Frey et al., 2009). Using a 4-point rating scale (1 = completely disagree; 4 = completely agree) the students had to each assess five statements on their individual interest in chemistry and biology. Participants' situational interest in the simulation and experiment-based activity was assessed via the questionnaire on situational interest developed and validated by Engeln (2004). The test used 12 items and participants could indicate their answers on a 4-point rating scale (1 = completely disagree; 4 = completely agree).

Internal Consistency of Used Instruments

We piloted the instruments for cognitive load, situational and individual interest with students ($N = 44$) from three different classes of the 13th grade (Table 5.2). Therefore, the students conducted the student lab day as planned and answered the questionnaires on a tablet computer. All scales showed sufficiently high reliabilities and could be used without modifications for the main study.

Table 5.2. Pilot study ($N = 44$ students): Summary of reliabilities (Cronbach's α) of used scales

Scales	Cronbach's α	No. of Items	Example Item
Interest in Biology	.898	5	I am interested in learning new things in biology
Interest in Chemistry	.909	5	I am interested in learning new things in chemistry
Cognitive Load	.662	2	How difficult was the simulation to understand?
Situational Interest	.832	12	I would like to learn more about the simulation/ experiments we worked on at this station

The content knowledge test was checked for validity with a group of 23 students from grade 12. The students carried out the student lab day as planned, but answered the questions in an open plenary session with us. Thus, some ambiguities (wording, specialist terminology) were removed afterwards. After the validation, we could determine the sufficiently high internal consistencies for the instruments used in our study (Table 5.3).

Table 5.3. Summary of reliabilities (Cronbach's α) of used scales

Scales	Cronbach's α	No. of Items	Example Item
Interest in Biology	.931	5	I am interested in learning new things in biology
Interest in Chemistry	.920	5	I am interested in learning new things in chemistry
Cognitive Load	.797	2	How difficult was the simulation to understand?
Situational interest	.777	12	I would like to learn more about the things we worked on in the simulation/experiment

5.5 RESULTS

All results were calculated using SPSS. We used t -tests to examine mean value comparisons. In case of more than one t -test for a scale, Holm-Bonferroni alpha-adjustments were made in order to avoid an inflation of the alpha-error.

5.5.1 Pre-Test Results

In the prior content knowledge questionnaire students achieved an average of 3.38 points ($SD = 2.46$) out of 18 possible points. This expectedly very low prior knowledge justifies further our research design which deliberately abstains from pre-post comparisons (see method section). The qualitative evaluation of the first open question showed that 83% of the students mentioned pollution by hazardous substances such as oil or plastic as the best-known danger for the Baltic Sea, 56% named consequences of overuse of the ecosystem and 54% named effects of climate change as a danger.

After a randomized grouping into two groups, analyses of mean prior knowledge, grades, and individual interests (Table 5.4) did not indicate any significant differences between the groups (all $p > .05$).

Table 5.4. Means (standard deviations) of independent variables for the later grouping

Scales	Group A	Group B	<i>df</i>	<i>t</i>	<i>p</i>
Prior knowledge (Points)	3.16 (2.44)	3.63 (2.47)	364	-1.81	.072
Grades in science subjects	2.95 (1.1)	3.01 (1.0)	362	-0.53	.599
Interest in biology	2.96 (0.66)	2.93 (0.64)	363	0.44	.664
Interest in chemistry	2.47 (0.67)	2.47 (0.7)	365	0.03	.978

5.5.2 Descriptive Values

Table 5.5 presents the descriptive values of the dependent variables of both groups. We did not find any significant effects of gender or age for any dependent variable. In the following, we use the mean value for the analyses of content knowledge. This procedure ensures a good comparability, since we used different numbers of items for the different levels of complexity.

Table 5.5. Means (standard deviations) of dependent variables for each group and method

	Group A		Group B	
	Experiments	Simulation	Simulation	Experiments
Overall content knowledge	0.48 (0.19)	0.77 (0.21)	0.70 (0.24)	0.66 (0.24)
Declarative knowledge	0.47 (0.18)	0.67 (0.18)	0.53 (0.15)	0.69 (0.19)
Basic interactions	0.61 (0.33)	0.80 (0.39)	0.86 (0.3)	0.74 (0.39)
Complex interactions	0.32 (0.26)	0.77 (0.38)	0.69 (0.41)	0.42 (0.35)
Cognitive load	2.70 (0.96)	3.21 (1.15)	3.00 (1.04)	2.66 (1.02)
Situational interest	2.79 (0.50)	2.65 (0.46)	2.60 (0.48)	2.66 (0.50)

5.5.3 RQ 1: Comparison of Hands-On Experiments and Computer Simulation

We compared the intermediate test results of the two groups to evaluate the effects of the individual methods (Figure 5.4). The analyses were done by mean value comparisons.

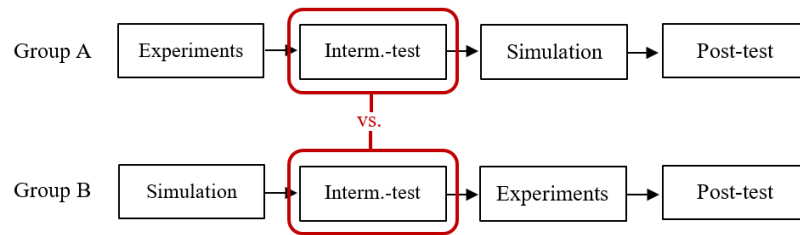


Figure 5.4. Graphical representation of the calculations for Research Question 1

a) Content Knowledge

The test results showed a significantly higher achievement by students who worked on the simulation compared to the experiments ($t(365) = -10.90, p < .001, d = -1.14$). Figure 5.5 gives an overview of the differences in average content knowledge between the methods for both groups. The content knowledge questionnaire was further divided into different levels of complexity. The intermediate test results showed that students could learn more at each level of complexity through working on a computer simulation than with experiments. For an overview of the means, standard deviations and statistic values of all levels of complexity of the knowledge questionnaire of the intermediate test results, see Table 5.6.

Table 5.6. Intermediate test results: Means (SD) of students' achievement in content knowledge test and corresponding values of the t -tests subdivided by levels of complexity for each group. All p -values are adjusted for alpha-inflation using Bonferroni-Holm correction

	Mean (SD) Experiments	Mean (SD) Simulation	df	t	p	d
Declarative knowledge	0.47 (0.18)	0.53 (0.15)	360	-4.275	< .001	-.45
Basic interactions	0.61 (0.33)	0.86 (0.3)	360	7.906	< .001	.83
Complex interactions	0.32 (0.26)	0.69 (0.41)	361	10.598	< .001	1.12

b) Cognitive Load

We found a rather low mean cognitive load for both methods measured on a 7-point Likert scale (Table 5.5). Nevertheless, the t -test of the intermediate test values showed a significantly higher cognitive load for working on the computer simulation compared to the experiments ($t(365) = 2.28, p = .023, d = 0.21$) (Figure 5.6).

c) Situational Interest

Taking into account a four-level Likert scale, working on both methods led to a medium situational interest (Table 5.5). The direct comparison of the two methods showed that the students achieved a significantly higher level of situational interest by working on the experiments than by working on

the simulation $t(365) = -3.80, p < .001, d = -.40$). See Figure 5.7 for an overview of the differences in mean situational interest between the methods for both groups.

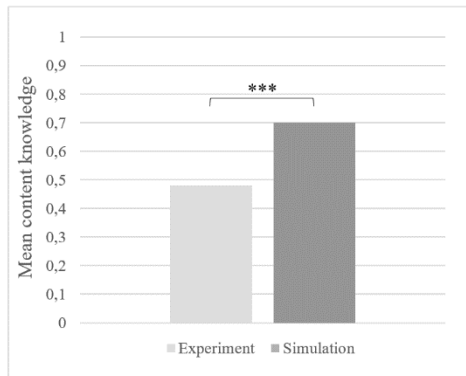


Figure 5.5. Intermediate test results: Differences in mean content knowledge between the methods (Group A: Experiments $N = 176$; Group B: Simulation $N = 169$)

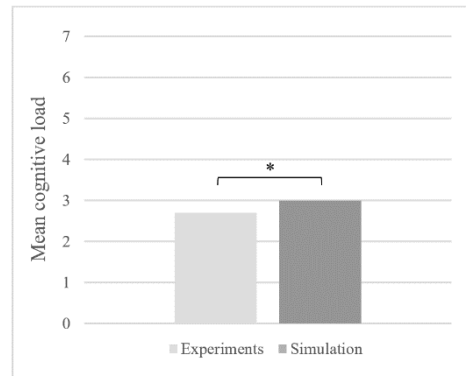


Figure 5.6. Intermediate test results: Differences in mean cognitive load between the methods (Group A: Experiments $N = 176$; Group B: Simulation $N = 169$)

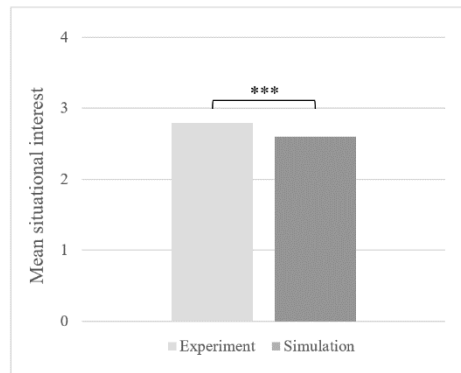


Figure 5.7. Intermediate test results: Differences in mean situational interest between the methods (Group A: Experiments $N = 176$; Group B: Simulation $N = 169$)

5.5.4 RQ 2: Comparison of Combined Approach and Single Use of Methods

To find out general effects of a combination compared to a single use of methods we compared the mean of both post-test values with the mean of both intermediate-test values (Figure 5.8). Therefore, the intermediate-test results show the effect of working with one method and the post-test results show the effect of working with two methods (independent of the type of method). This calculation provides evidence whether there are transfer effects in a combined approach (transfer effect = effect in first method influences effect in second method).

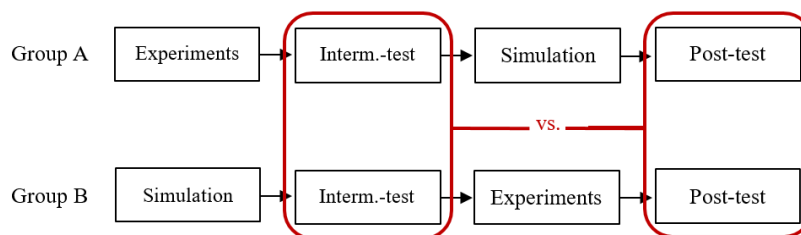


Figure 5.8. Graphical representation of the calculations for Research Question 2

In addition to this general analysis, we compared the post-test results of one group with the intermediate test results of the other group. These calculations show the effects of a preceding additional method compared to the single use of this method (Figure 5.9).

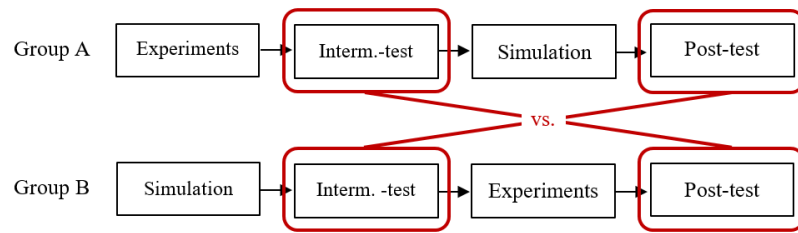


Figure 5.9. Graphical representation of the calculations for Research Question 2

a) Content Knowledge

In general, students learned more by a combination than by a single use of methods ($t(344) = 9.40$, $p < .001$, $d = 1.01$). The more detailed investigation of the effects of a preceding method (Figure 9) showed significantly higher means for students' overall content knowledge achievement after conducting first experiments and second a simulation (Group A) vs. using the simulation alone ($t(343) = 2.87$, $p = .004$, $d = .31$). However, considering the different levels of complexity, this only applies to declarative knowledge ($t(343) = 7.66$, $p < .001$, $d = .83$). We also found higher achievement for the overall content knowledge after conducting first a simulation and second experiments (Group B) vs. using the experiments alone ($t(362) = 5.809$, $p < .001$, $d = .61$). Regarding the different levels of complexity, we found that these findings also only applied to declarative knowledge ($t(360) = 5.858$, $p < .001$, $d = .62$). Concerning basic and complex interactions, we found no differences between learning with two methods compared to learning with one method (all $p > .05$).

b) Cognitive Load

The general comparison showed no difference in cognitive load of students between the mean of the intermediate test compared to the mean of the post-test. A preceding work phase also had no effect on the cognitive load compared to a single use of the methods for both groups.

c) Situational Interest

The general comparison showed no difference in situational interest of students between the mean of the intermediate test compared to the mean of the post-test.

A preceding experimental work phase (Group A) showed no effects compared to working on a simulation alone regarding the development of situational interest. When the simulation was done before the experiments (Group B), however, the students developed less situational interest than when they only did the experiments ($t(364) = -2.414$, $p = .016$, $d = -.25$) (Figure 5.5).

5.5.5 RQ 3: Comparison of the Different Order of Methods

Regarding content knowledge achievement, we compared the post-test values of both groups to answer this research question (Figure 5.10). These values provide information about the overall (accumulated) content knowledge achievement after the combined approaches.

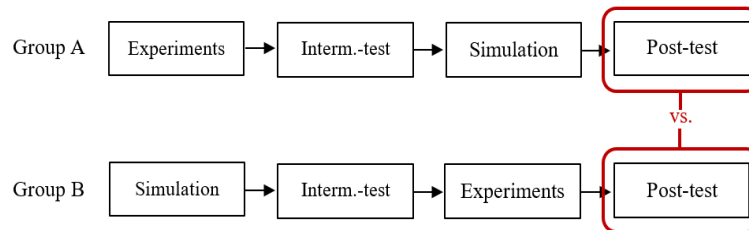


Figure 5.10. Graphical representation of the calculations for Research Question 3 a)

For the scales cognitive load and situational interest, we compared the mean value of the intermediate and post-test of Group A with the mean value of the intermediate and post-test of Group B (Figure 5.11). A comparison of these group averages is possible and appropriate here, since both instruments measure the effects in direct relation to the students' activities. No transfer effects from one method to the other were expected. In contrast, a comparison of these group averages does not appear to be appropriate for content knowledge, since there are transfer effects (see above: transfer effect = effect of first method influences effect of second method).

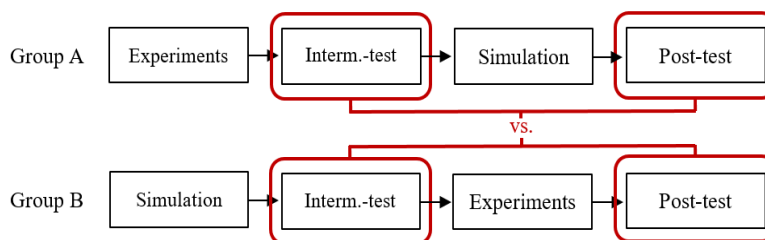


Figure 5.11. Graphical representation of the calculations for Research Question 3 b) + 3 c)

a) Content Knowledge

The comparison of the post-test values showed significant higher learning outcomes in Group A compared to Group B ($t(343) = 4.41, p < .001, d = 0.43$) as shown in Figure 5.12. Asking for the preferred order of methods to learn about the future of the Baltic Sea, 47.43% of students voted for order of Group A, 39.58% for order of Group B and 12.99% of students did not care.

b) Cognitive Load

The comparison of the group averages showed no significant difference in cognitive load between the two groups.

c) *Situational Interest*

Comparing the group averages, we found a significantly higher situational interest when working first on experiments and second on a simulation (Group A) compared to the other way around (Group B) ($t(365) = -2.685, p = .008, d = -.28$) as shown in Figure 5.13.

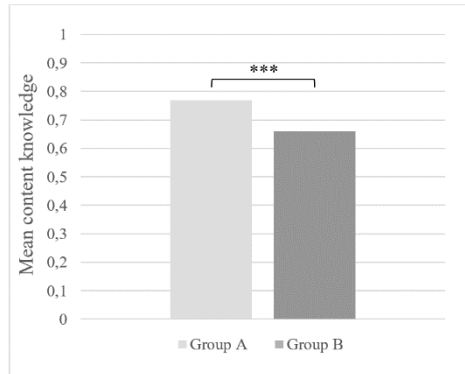


Figure 5.12. Post-test results: Differences in mean content knowledge between the groups

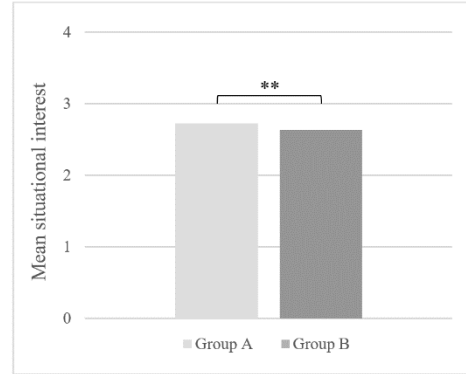


Figure 5.13. Group averages: Differences in mean situational interest between the groups

5.6 DISCUSSION

This study shows effects of a combination of hands-on experiments and an interactive computer simulation as learning tools on students' content knowledge achievement, cognitive load and situational interest. The aim of this work was

- 1) to investigate individual effects of the two methods,
- 2) to compare the effects of a single use of a method with a combined approach, and
- 3) to investigate the effects due to the order of methods in the combined approaches.

The results are explained and discussed in detail below and followed by resulting implications.

5.6.1 Pre-Test Results: Students Had Low Prior Knowledge

As expected, students' prior knowledge was very low. Although climate change (in particular regarding marine ecology) is an important current topic in the societal discourse, it has only slowly been included in school curricula, at least in Germany. This is further supported by the fact that most students consider pollution – and not the effects of climate change – to be the greatest threat to the Baltic Sea. This demonstrates the importance of activities in science education to communicate current marine biology issues (especially in terms of climate change) as such topics often cannot be adequately conveyed in school.

5.6.2 RQ 1: Comparison of Hands-On Experiments and Computer Simulation

a) Simulations Conveyed More Content Knowledge than Experiments at All Levels of Complexity

Although the simulation caused higher cognitive load, which negatively affects the learning outcome – as has often been shown before (Jong, 2010; Jong & van Joolingen, 1998; Köck, 2018) – students were still able to learn more through the simulation than with the experiments. The large effect size ($d = -1.14$) when comparing simulation and experiments makes the benefits of learning from simulations particularly visible. These results contradict our hypothesis, even though it was based on the majority of the established research literature (see Section 5.2). One explanation for this may be the great suitability of simulations for conveying complex issues – as in our study – which compensated for the possible negative influence of cognitive load. Additionally, the appropriate instructive support during the simulation might be used as an explanation. Results from research literature show that instructional support effectively promotes knowledge acquisition when learning with computer simulations (Eckhardt et al., 2018; Mayer, 2004; Rutten et al., 2012). Especially for students with little prior knowledge – as those in our study –, instructional support offers effective support for successful knowledge acquisition (White & Frederiksen, 1998). Evidence also indicates the suitability of computer-based tools in comparison to analogous tools for conveying content knowledge (Lichti & Roth, 2018; Scheuring & Roth, 2017). For example, Ryoo and Linn (2012) stated that computer simulations can potentially improve learners' understanding of abstract biological phenomena. A study by Paul and John (2020) shows that skills for complex thinking processes of secondary school students are more improved by the use of computer simulation than by the activity-oriented method.

The described findings apply, contrary to our hypothesis, to all levels of complexity. Only the effect sizes indicate that simulations are particularly well suited for conveying complex content: The more complex the content was, the greater the effect of the advantage of simulations over experiments. For declarative knowledge only a medium effect size ($d = -.45$) could be found, whereby simulations had a large advantage over experiments to convey basic interactions ($d = .83$) as well as complex interactions ($d = 1.12$). This tendency might indicate that our hypothesis was not completely wrong, as experiments are still most likely to be recommended for teaching basic knowledge – even though simulations can also convey this knowledge with appropriate instructional support. Aiming to teach particularly complex current topics such as SSI as well as basic content, computer simulations thus pose an important tool and should be used more often in school and out-of-school science education.

b) Simulation Caused Higher Cognitive Load Than Experiments

As expected, the evaluation of the individual methods showed higher cognitive load by working on the simulation compared to working on experiments. For learners, the non-linear structure of a digital learning environment often “costs” some cognitive resources (Jong, 2010). Furthermore, the simulation might have generated split-attention effects (having to keep in mind many elements or having to observe several changes on different places on the screen) and thus negatively influenced the cognitive load (Kalyuga, 2007). These demands are higher for simulations than for experiments, which are carried out step by step on the basis of a detailed experimental description. The small effect size of the difference ($d = .21$) and the generally low cognitive load (experiments $M (SD) = 2.7 (.96)$ and simulation $M (SD) = 3.0 (1.04)$; 7-level rating scale) may be due to the didactically well prepared instructional support for both methods.

c) Experiments Promoted Situational Interest More Than Computer Simulation

As expected, the students’ situational interest is at least at a medium level for both methods. Contrary to our hypothesis, the direct comparison of the two methods showed that the students gained more situational interest through the experiments than through the simulation with a medium effect size ($d = -.40$). First, the incorrect hypothesis may be due to the relatively old and possibly outdated existing literature on the development of interest in learning with computer simulations (e.g. Jain & Getis, 2003; Rutten et al., 2012). Students today are used to digital (learning) environments and are probably no longer easily excited by their novelty, as may have been the case a few years ago. Hence, it proves more difficult to increase students’ situational interest via the digital medium itself. According to Mitnik, Recabarren, Nussbaum, and Soto (2009), the increased motivation of the experiment group was based on the immersion in the activity which stimulated the engagement and participation of the students during the whole work phase. Second, experiments represent something unusual. In everyday school life teachers often lack time, equipment, and opportunities to let students conduct experiments on their own. Therefore, the hands-on activities could be something special having a strong influence on their situational interest. This is in line with the research of Lin et al. (2013) which showed a positive influence of novel or striking activities on the situational interest of students.

5.6.3 RQ 2: Comparison of Combined Approach and Single Use of Methods

For the calculations carried out here, the mean values of different times of measurement of the two groups were compared with each other (Figure 5.9). We are confident that the different test times of the two groups are comparable because the grouping was randomized and the results of the pre-tests showed no differences in the independent variables (Table 5.4).

a) Content Knowledge: Two Methods Are Better Than One/Complementary Suitability of Experiments for Conveying Declarative Knowledge

The conclusions from Research Question 1a) led to the question why a second method like experiments are needed at all when educators have the main goal of knowledge acquisition. Wouldn't it be sufficient to use only a simulation? With a very large effect size ($d = 1.01$), we could show that students learned significantly more by combining two methods than with one – as we expected. We assume that the knowledge achievement of the first method had a positive influence on the knowledge achievement of the second method. Therefore, the higher achievement by the combination compared to single use was probably due to (positive) transfer effects. This finding is of somewhat limited value as there is obviously a different time-on-task between conducting one and two methods. Still, rather than an overall comparison of using one versus two learning tools, we aimed to look for specific advantages both types of learning could bring to the table. Therefore, we can state, that a preceding experiment offered significant advantages in learning especially when a multilevel knowledge acquisition is required. Although the effect of the learning advantage of combining first experiments and second simulation had only a medium effect size compared to simulation alone ($d = .31$), it is of great interest what kind of knowledge was additionally fostered by the experiments: The learning increase using the combined approach compared to the single use of simulation was mainly based on the increase of declarative knowledge ($d = .83$). The experiments were thus able to strongly promote declarative knowledge in particular. This might be because the experiments only focused on one change, one organism, and one further impact at a time. The students were thus better able to understand the basic content than if everything was presented at once (as the simulation did). This highlights the complementing suitability of experiments to computer simulations in learning multilevel interactions. In their study, Hancock and Rummerfield (2020) found supporting evidence for this by showing that students who took part in a hands-on activity before a computer simulation showed better achievements compared to those who only did computer simulations. This further emphasizes the already mentioned suitability of experiments to convey basic knowledge in particular (Köck, 2018; Mönter & Hof, 2012). In order to understand complex interactions, such as the effects of climate change on ecosystems and their communities, students must first acquire declarative knowledge about the various factors of the system. Then they are able to transfer the knowledge into a wider context. It is more difficult to understand complex interactions if they do not have this basic knowledge.

b) Cognitive Load Unaffected by Combination

Our hypothesis that the cognitive load should be minimized by repeated working on the same content proved not to be correct – the already known content seemingly did not reduce the extraneous load. The instrument measured the cognitive load in direct relation to the activity carried out. The effects of the individual methods therefore exceeded any transfer effects.

c) Simulations Not Necessary for Promoting Situational Interest

Contrary to our hypothesis, we found that students could not gain more situational interest by working with two methods compared to only one. Similar to our assumptions on cognitive load, the individual effects of the methods seemed to exceed transfer effects. Nevertheless, the more detailed analysis of the two groups showed that even if no general effects were detected, negative transfer effects were possible (Group B). This is probably because the lower students' situational interest in the first working phase led to a lower basic motivation for any activity itself. With the goal of motivating students, a preceding simulation phase is therefore not necessary but rather contradictory. Even if positive transfer effects do not seem to exist, negative effects should be avoided if possible. Therefore, educators should either use hands-on activities only, or implement simulations as a second working phase.

5.6.4 RQ 3: Comparison of the Different Order of Methods***a) First Experiments and Second Simulation Seemed to be the Best Way to Convey Content Knowledge***

Since the students in Group A ended up learning more than in Group B, we conclude that it is more effective for learning achievement to do hands-on experiments first and then a computer simulation afterwards than the other way around. Our hypothesis was confirmed as students' achievement was higher when they first learned basic processes and then observed and understood the findings on a systematic level (for a more detailed explanation see our discussion in Section 5.6.2. a).

Higher cognitive competencies of the participants of Group A could be excluded as the mean value comparisons of prior knowledge and grades in the science subjects between the two treatment groups showed no significant differences.

b) Cognitive Load Unaffected by Order of Methods

As we predicted, there was no difference in overall mean cognitive load between both orders of methods. Following our considerations regarding transfer effects show (see Section 5.6.2. b), the order of combination did not have any additional influence on the development of cognitive load. In terms of cognitive load, no advice for any order of methods can be concluded based on our research.

c) Higher Level of Situational Interest if First Experiments and Second Simulation than the Other Way Around

In order to achieve the greatest possible effect on the overall situational interest, we advise to work first on experiments and second on simulation (Group A). It was only a small effect ($d = -.28$), but the combination of experiments first and simulation second (Group A) seemed to enhance more overall situational interest than the other way around, contrary to our hypothesis. This could be due

to the fact that the negative transfer effects (see Section 5.6.2. c) resulted in a lower overall mean value of situational interest.

The situational interest might have an influence on the development of the individual interest (Krapp & Prenzel, 2011). Additionally, as already mentioned in previous research literature (Krapp & Prenzel, 2011; Potvin & Hasni, 2014; Schiefele et al., 1992), content knowledge gain depends on individual interest. This correlation between situational and individual interest as well as the development of content knowledge indicates that educators should always provide the highest possible level of situational interest during their activities. If educators want to use a combination of methods for better knowledge acquisition following the considerations presented in Section 5.6.2. a), they should consider these assumptions and use the order of first experiments and second simulation.

In addition to the effects already described in Section 5.6.3. a), the higher content knowledge achievement in the post-test of Group A compared to Group B might also be due to the learning-promoting factor of increased situational interest in this group. We conclude that students should work on the experiments before the simulation in order to enable better learning due to the resulting higher level of interest.

Since there was no difference between the two treatment groups in terms of individual interest in biology and chemistry, this indicates that the observed results in situational interest of the groups are independent of their prior individual interest.

5.7 LIMITATIONS

The investigation of effects of a combined approach of simulation and experiments has been investigated here only on the basis of one student laboratory day in the field of marine ecology. Further research is therefore required to determine whether the results can also be applied to other areas of science.

A supervisor supported the students with each method. The individual supervisor's behavior may have deviated from each other and thus indirectly influenced students' achievement and motivation. However, since all supervisors received a schedule of each station containing the same guidelines with regard to the topics and contexts to be dealt with, this effect is expected to be minimal.

Although the tasks that the students had to complete during the two methods were the same, the medium was different. During the experiments the script had to be completed in paper form and during the simulation on the tablet. The difference between the analog and digital medium may have resulted in different motivation among the students. Since filling out digital worksheets is certainly still very new in everyday school life, this may have motivated the students to write more

than on the conventional paper. As a result, the students may have worked more detailed and thus may learned more. However, this effect is not expected to be too great and the large effect sizes when comparing the two methods should not be detracted by this.

The transferability of the results with regard to the simulation is only to be expected for simulations of a similar design. The simulation used here was based on real scientific data and showed a high degree of interactivity in addition to its attractive modern design. A low cognitive load was possible due to the well-used instructional support. If other simulation tools do not meet these requirements, transferability is not to be expected and the individual conditions have to be strictly checked.

The comparison of the effects between a combination and the use of a single method is limited by the time on task effect. With high probability, a part of the learning advantage of a combination of methods can be explained by the doubled working time. Nevertheless we have decided not to use a control group that uses the same method twice. Letting students do the same thing twice would have had a clear effect on the situational interest and, moreover, seemed to be practically unacceptable.

Unfortunately, the reliability of the cognitive load scale was relatively low ($\alpha = .662$). This questions somewhat the trustworthiness of the conclusions about cognitive load, although several studies validated and used this instrument before (Naismith & Cavalcanti, 2015; Sweller, 2011). In the future, a more sophisticated measurement could better be used, such as the dual-task measurement (Brünken et al., 2004) or psychometric scales that distinguish between categories of cognitive load (Leppink et al., 2014).

5.8 IMPLICATIONS

In conclusion, the combination of experimental and simulation-based learning tools tested here represents an effective learning opportunity for complex current topics such as SSI in science education. Especially the order of first experiments and second simulation seemed to be advantageous. In addition to these empirical results, the students' self-report also leads us to the conclusion that this order seems to be the more effective one. This approach offers the opportunity to combine cognitive and motivational advantages in a profitable way. Therefore, we recommend that such a combination should be used more often in science education. Beyond the described advantages for content knowledge and situational interest, this approach may provide a better insight into authentic science research. This may contribute to a better understanding of scientific research, which is a very important factor in enabling students to actively participate and engage in the societal discourse. Furthermore, media competences are promoted on different levels, which is of great importance in today's multilevel society.

Moreover, our investigation has also shown that the implementation of such a combination is very demanding in terms of expertise, time and technical resources. If for practical reasons the use of

two different methods is not feasible, the single use of a (well-developed!) simulation is to be preferred when conveying content knowledge is the main focus. If promoting interest is the focus, experiments might be preferred.

If educators choose a simulation, intensive preparation is extremely important as developing science-based simulations requires a great deal of effort. This is best done in a multidisciplinary team. Further instructional support should be implemented in any case. Otherwise, learning benefits may be lost due to a high cognitive load. These requirements lead to the fact that such a combined use is especially recommended for out-of-school learning locations. In school, existing materials should be used and attention should be paid to a good didactic integration. Teacher trainings might be important in this case to ensure sufficient content and media competencies.

The results also make it clear that besides the very important enhancement of digital learning skills, hands-on activities should not be forgotten. Especially in the context of promoting interest, hands-on experiences are very important and should stay an integral part of science teaching in school and out-of-school education.

6 HOW MUCH DO STUDENTS TRUST IN SCIENCE?

A STUDY OF TRUST IN SCIENCE AND SCIENTISTS AMONG SECONDARY SCHOOL STUDENTS IN OUT-OF-SCHOOL LEARNING ACTIVITIES

6.1 ABSTRACT

Research on science outreach activities is often located in the interface between science communication and science education. The transferability of aims and objectives of one research field to the other often offers great potential. The widely recognized aim of "trust in science" in science communication is still less discussed in science education. However, when teaching emotionally charged scientific topics such as climate change, vaccines or genetic engineering, students' trust in science is of great importance. This paper presents two studies ($N_{StudyI} = 443$; $N_{StudyII} = 333$) to gain insight into the level of trust in science among secondary school students and to investigate the impact of two outreach activities on the development of trust in science. Results showed that the mean level of trust in science among school students is similar to the level among university students. We found a trust-enhancing effect of the interventions exclusively for students with a low prior level of trust. However, there is evidence that a high level of trust in science can support learning in science outreach activities. A closer look at the used learning methods indicates that trust in science can be promoted especially by science-based computer simulations compared to hands-on experiments. In conclusion these studies provides empirical data on interactions between levels of trust and further learning outcomes after working with science outreach activities. Increasing the level of trust in science seems to be especially important for students who have low level of trust (low-trustors) in order to prevent negative social tendencies.

6.2 INTRODUCTION

The Corona virus - a hoax or hyped-up scaremongering? 5G radiation responsible for Corona epidemic and microchips in vaccinations? Misinformation and conspiracy theories have been part of the public discourse not only since the global Corona pandemic. Misinformation partly even originates from unserious scientists or is based on scientific principles to gain convincing legitimacy (e.g. Díez Arroyo, 2013). But how can learners and laypeople distinguish between misinformation and scientific evidence?

In our modern science-based society, with its highly evolved division of cognitive effort, the individual remains a layperson in most areas of knowledge (Bromme & Thomm, 2016). It is important for each individual to be able to judge what the truth is, rather than simply trusting what you are told (Hendriks, Kienhues, & Bromme, 2016c). Therefore, one main goal of science education should not be to achieve blind trust in scientific information or scientists per se. Rather, the aim should be to increase trust in the process of scientific knowledge acquisition. To trust the process of science, one must first understand what defines authentic science. Therefore, science education should give insights into the fundamental principles of scientific knowledge, practice, and reasoning (Gräber, Nentwig, & Nicolson, 2002). Students should understand the nature of science, scientific terms and concepts, and the meaning of science's interaction with society – summarized under the term scientific literacy. The OPECD PISA Framework defined scientific literacy as „the ability to engage with science-related issues, and with the ideas of science, as a reflective citizen” (OECD, 2017, p. 22). Scientific literacy often demands a critical and reflective approach to knowledge and information. However, the goal is not to generally question everything, but to enable students to engage in reasoned discourse about science and technology based on fundamental knowledge about and trust in science. Bromme (2020) defined this critical trust as "informed trust" and emphasized that not only basic knowledge, but above all knowledge about science itself as relevant factors.

For active participation in society, neither blind trust nor a fundamental questioning of every scientific finding is useful. Students, therefore, should learn to distinguish when to question emerging and uncertain scientific contexts and, in turn, when and why to trust in science (Bryce & Fraser, 2014; Fensham, 2014).

“Doubting everything or believing everything are two equally accommodating solutions, either of which saves us from reflection.” (Henri Poincarés , La Science et l’Hypothèse, quoted by Allchin (2014))

Outreach activities often aim to increase scientific literacy. To what extent do such activities also influence the development of students' trust in science? This paper presents two studies to investigate the influences of two outreach activities on the development of trust in science. First, an existing instrument for measuring trust in science and scientists was adapted for use with secondary school students. Afterwards, we investigated the students' level of trust in science and the influence of outreach activities on the development of trust. Since indications suggest that authentic insights into science can increase trust in science (Hendriks, Kienhues, & Bromme, 2016a), we additionally investigated the effects of different science-based learning methods (experiments and simulations). We designed two studies to ensure the independence of results from the learning location and to examine effects of different approaches of learning methods.

6.2.1 Definition of Trust (in Science)

Trust is described as a kind of assumption about others. When people (the trustors) are dependent on persons or organizations (the trustees), and when they are willing to accept the risks associated with this dependence, they trust these persons or organizations (Blöbaum, 2016; Bromme & Thomm, 2016; PytlikZillig & Kimbrough, 2016). This dependency describes the willingness to be vulnerable to another person (Mayer, Davis, & Schoorman, 1995). When this theory is applied to science, it means that the good that the trustee provides to the trustor is "knowledge", and the risk to the trustor is his vulnerability to a lack of truth or validity of that knowledge (Hendriks et al., 2016c). People depend on the knowledge of experts when it comes to developing a personal opinion on science-based topics and making decisions about them (Hendriks et al., 2016c). In terms of science, trust can be described as a perception of scientists as credible, likely to tell the truth and share the public's interest (National Academies of Sciences, Engineering, and Medicine, 2015). Trust in science is useful and necessary for the functioning of a science-based society (Arimoto & Sato, 2012; Hendriks et al., 2016c; Sztompka, 2016).

Trust is a complex construct that includes affective and cognitive dimensions (Dunn & Schweitzer, 2005; Mayer et al., 1995). Thus, trust is strongly influenced by emotional perceptions and can itself have a major impact on people's perception, especially in emotionally charged scientific topics (Dunn & Schweitzer, 2005; Romano, 2003). Examples of such topics in recent societal discourse are genetic engineering (Broughton & Nadelson, 2012), climate change (Dunlap & McCright, 2011), vaccines (Keelan, Pavri, Balakrishnan, & Wilson, 2010), or restrictions due to the Covid-19 pandemic (Plohl & Musil, 2020). Higher trust in science and scientists is likely to increase acceptance in these areas (Nadelson & Hardy, 2015).

6.2.2 Factors Influencing Trust in Science

To gain insight into publics' trust in science, some studies have already assessed the level of public trust in science in general (e.g. Besley, 2014; Wissenschaft im Dialog, 2019). For example, the Wellcome Global Monitor was conducted in 144 countries, making it the largest study to date examining attitudes toward science. The calculated trust index shows medium trust for more than half of EU citizens (61%), high trust for 25% and low trust in science for 11% (Gallup, 2019). Moreover, some scientists have tried to identify factors that influence this complex construct (e.g. Fiske & Dupree, 2014; Hendriks et al., 2016c). Findings suggest, for example, that people with privileged socio-demographic identities more trusted in science than those with marginalized identities (American Academy of Arts and Sciences, 2018; Funk, Rainie, & Page, 2015; Gauchat, 2012). In addition, Nadelson et al. (2014) found a positive correlation of trust in science with the number of years studying science. The vast majority of the public recognizes science as an important tool for understanding the world and acknowledges that science is necessary to make effective decisions in their lives (Fischhoff, 2014) – they trust in science and scientists (Besley, 2014; Wissenschaft im Dialog,

2019). Nevertheless, there are some people who hold beliefs that contradict the best available scientific knowledge (Funk et al., 2015; Leiserowitz et al., 2019). Existing research identified religious beliefs (Nadelson et al., 2014), conservative political tendencies (Gauchat, 2012; Myers et al., 2017), ideological motivations (Lewandowsky, Gignac, & Oberauer, 2013), and poor scientific literacy (Lombrozo, Thanukos, & Weisberg, 2008; Miller, 2004) as possible causes for the lack of trust some have in science. Furthermore, there is evidence that a low level of trust in science is a good predictor of people believing in conspiracy theories and paranormal beliefs (Fasce & Picó, 2019; Irwin, Dagnall, & Drinkwater, 2016; Requarth, 2017) as well as for science denialism (Lewandowsky et al., 2013; Nadelson & Hardy, 2015; Omer, Salmon, Orenstein, deHart, & Halsey, 2009). These *unwarranted beliefs* (Fasce & Picó, 2019) have risen in prevalence with dangerous risks for society (Chigwedere, Seage, Gruskin, Lee, & Essex, 2008; Gangarosa et al., 1998; Johnson, Park, Gross, & Yu, 2018). Enhancing public trust in science is therefore very important to ensure the functioning of a modern society based on science and technology. Which options exist to promote trust in science?

6.2.3 Measures to Increase Public Trust in Science

On the one hand, it seems that public trust in science can be influenced by the way scientists themselves communicate. For example, trust in science can be increased if scientists communicate associated uncertainties or societal contexts in addition to the scientific evidence (Hendriks et al., 2016a, 2016b; Jensen, 2008). Furthermore, it seems to have a positive effect on public trust in research findings if there is open access to data and transparent, independent review of research (Funk, Hefferon, Kennedy, & Johnson, 2019). On the other hand, there are possibilities for intentional enhancement through educational activities in science-related institutions: science communication activities with close ties to science are a promising way to go (Kappel & Holmen, 2019). A good starting point for promoting trust in science already among young people could therefore be activities in the field of science communication such as outreach activities in science-related institutions (e.g. science museum, student laboratory) where they get an authentic insight into scientific knowledge acquisition and understand how scientists think and act.

6.2.4 Measurement of Trust in Science

There are various instruments that already measure the multifaceted construct “trust in science” in different fields of research (Anderson, Scheufele, Brossard, & Corley, 2012; Brossard & Lewenstein, 2010; Farias, Newheiser, Kahane, & Toledo, 2013; Hall, Camacho, Dugan, & Balkrishnan, 2002; Hartman, Dieckmann, Sprenger, Stastny, & DeMarree, 2017). One of the most frequently used instruments is the Trust in Science and Scientists Inventory (TSSI) by Nadelson et al. (2014): A 21-item trust scale to measure generic (not domain-specific) trust in science and scientists. The TSSI was used so far to determine the influence of political attitudes and religious beliefs on trust in science (Blankenship & Stewart, 2019; Slater, Huxster, & Bresticker, 2019) or to identify factors

that influence the development of conspiracy theories and science denialism (e.g. Nadelson & Hardy, 2015). Currently, there is much research on the relationship between trust in science and the acceptance of Covid-19 protective measures (e.g. Plohl & Musil, 2020; Szczuka, Meinert, & Krämer, 2020). The instrument's use was located in the fields of social psychology and science communication and the target group so far has been the general public (recruited from various contexts, age of the participants 18-65).

The level of trust in science among school students and the relationship between trust in science and learning success or social demographic data in science education have so far received little attention. In the school context, the construct *trust* has primarily been measured as interpersonal social relations (Forsyth, Adams, & Hoy, 2011; Liou & Daly, 2019; Murphy-Graham & Lample, 2014; Ream, Lewis, & Echeverria, 2014; Watson, Daly, Smith, & Rabin, 2019) or in the form of organizational trust in schools (Černe, Nerstad, Dysvik, & Škerlavaj, 2014; Smetana, Wenner, Settlage, & McCoach, 2016). However, it has rarely been investigated as *trust in science*.

6.3 DESIGN AND METHODS

Our studies were carried out as part of the Leibniz ScienceCampus Kiel Science Outreach Campus (KiSOC) project, which aims to investigate success factors for understandable and motivating science communication. A key aspect of a Leibniz ScienceCampus is the close collaboration between Leibniz institutions and universities, which gives this project a special interdisciplinary character. Marine ecology researchers, science educators and psychologists worked together in a co-design to develop and evaluate the outreach activities that were carried out in the Kieler Forschungswerkstatt (joint student laboratory of the Leibniz Institute for Science and Mathematics Education and Kiel University).

Both studies were conducted using a simple experimental research design (Figure 6.1). In the pre-test, we assessed socio-demographic data as well as individual interest in biology and chemistry and the level of trust in science and scientists. The post-test analyzed the effectiveness of the outreach activities regarding content knowledge achievement and the level of trust in science and scientists.

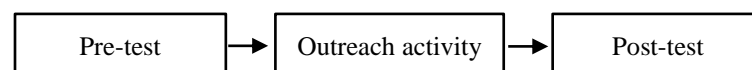


Figure 6.1. Evaluation design of both studies

6.3.1 Research Focus

This paper focuses on different research foci (RF):

RF 1: The adaptation and validation of instrument TSSI by Nadelson et al. (2014) to use with secondary school students

RF 2: The investigation of the level of trust in science of secondary school students and dependencies on socio-demographic information

RF 3: The investigation of the impact of outreach activities on the development of trust in science

RF 4: The investigation of the relationship between learning success and trust in science

RF 5: The investigation of the effects of different learning methods (hands-on experiments and computer simulation) on trust in science

6.3.2 Description of the Outreach Activities

The two outreach activities presented here were similar in structure, overall topic, objectives, target group and evaluation design but differed in duration, learning location and complexity of the topic (Table 6.1). In each case, scientists of marine ecology, media psychology and education developed the interventions together in a co-design. Due to the fact that the investigations were identical in terms of design and procedure, they show a high degree of comparability. Climatic and anthropogenic changes in marine ecosystems served as subject matter. The interventions were designed for school students of Grade 10 to 13. In both studies, hands-on experiments and an interactive computer simulation were used as learning methods. The first study focused on the comparison of the two methods. Students were randomly assigned and worked on the same content either with experiments (Group A) or with a simulation (Group B). The second study focused on the combination of the two learning methods. Again, students were randomly assigned and worked on the same content with a combination of either first experiments and second simulation (Group C) or the other way around (Group D). See Krüger et al. (submitted) for a more detailed description of the interventions.

Table 6.1. Overview of the conducted outreach activities in Study I and Study II

	Outreach activity Study I	Outreach activity Study II
Location	School	Student laboratory
Thematic issue	Ocean acidification and impacts on calcifying organisms	4 anthropogenic changes of the Baltic Sea and impacts on ecosystem and societal level
Duration	1.5 hours	5 hours
Participants	<i>N</i> = 443 Grade 10-13 Mean age: 17.58	<i>N</i> = 333 Grade 10-13 Mean age: 17.02
Learning methods	Group A: Experiments Group B: Simulation	Group C: 1 st Experiments + 2 nd Simulation Group D: 1 st Simulation + 2 nd Experiments

We conducted two studies for several reasons. First, we wanted to confirm the independence of the results from the learning location. We also investigated whether the duration of the outreach activity could influence the development of trust. With regard to the effects of the different methods, we chose a direct comparison of the two methods in the first study (experiments versus simulation) and a comparison of the combined use of the methods in the second study (experiments + simulation versus simulation + experiments).

6.3.3 Evaluation Methods

Socio-Demographic Data

We assessed socio-demographic data like age, gender, marks in science subjects (biology, chemistry, and physics), subject focus, and individual interest in biology and chemistry. In order to gain a general impression of students' achievement in the science subjects, we calculated a mean value from the marks of the three science subjects. At German schools, it is typical that secondary school students focus on a thematic area (e.g. biology, chemistry, art, languages, sports, economics, etc.). We divided the subject focus into two groups: science-related (biology, chemistry, physics, general science) or non science-related (art, languages, sports, economics, etc.) subject focus. For measuring individual interest we adapted the PISA instrument "pleasure and interest in science" (Frey et al., 2009) each for interest in biology and chemistry. The students had to assess five statements each using a 4-point rating scale (1 = completely disagree; 4 = completely agree). For the calculations, the two scales were combined, since we were interested in general interest in this area, independent of the specific subject.

Knowledge Achievement

We developed and validated a new questionnaire because no established test existed for these extra-curricular topics. The tests were developed on the basis of existing knowledge tests in chemistry (Höft et al., 2019), the questions each represented the different content areas of the two studies. Most of the items were multiple-choice, but open-ended questions also were included to get a better insight into students' multilevel knowledge achievement. In Study I, students could score up to 15 points; in Study II, students could reach 27 points. See Krüger et al. (submitted) for a more detailed description of the development of the knowledge questions.

Trust in Science and Scientists

We measured trust in science and scientists using the Trust in Science and Scientists Inventory (TSSI) by Nadelson et al. (2014). The original scale included 21 items and has proven to be highly reliable and valid for use with college students (Cronbach's alpha of .86). Thus, the instrument had to be adapted and tested in terms of usability for school students before being used in the studies.

6.3.4 Participants

The participants were $N_{StudyI} = 443$ and $N_{StudyII} = 367$ students from 40 German secondary schools with an average age of $M_{StudyI} = 17.58$ ($SD = 1.41$) years and $M_{StudyII} = 17.02$ ($SD = 1.20$) years. The gender ratio was almost balanced (Study I: 57 % female and 43 % male; Study II: 54 % female and 46 % male). Almost 2/3 of the participants attended a grammar school and 1/3 a community school. About half of our participants had chosen science-related courses (Study I: 45.1%; Study II: 54.8%) and the other half non-science related courses. The students had well to medium average marks in science subjects ($M_{StudyI} = 2.55$ ($SD = 0.84$); $M_{StudyII} = 3.0$ ($SD = 1.07$); on a scale of 1 = very good - 6 = inadequate). Interest in biology ($M_{StudyI} = 2.91$ ($SD = 0.72$); $M_{StudyII} = 2.95$ ($SD = 0.65$) and chemistry ($M_{StudyI} = 2.31$ ($SD = 0.79$); $M_{StudyII} = 2.47$ ($SD = 0.68$)) can be regarded as high to medium-high on a four-level Likert scale.

6.4 RESULTS

6.4.1 RF 1: Adaptation and Validation of the TSSI

The 21 items developed by Nadelson et al. (2014) have been used without any content structuring so far and there was no evidence for any interrelation between them. Previous studies already used only selected items of the instrument, but neither provided a statistical nor a content explanation for their selection (Blankenship & Stewart, 2019; Kingsley, Oliver, & van Kranendonk, 2017; MacDonald et al., 2020). Our intention was to represent the 21-item variable set of the TSSI by a few independent factors with statistical and content-related justification. On the basis of 368 data sets of the first survey of Nadelson et al. (2014) we analyzed the structure of the instrument using an explorative factor analysis.

Both the Bartlett-test (Chi-square (210) = 2633.17, $p < .001$) and the Kaiser-Meyer-Olkin Measure of Sampling Adequacy ($KMO = .902$) indicated that the variables were suitable for factor analysis. The main component analysis with varimax rotation indicated four factors with eigenvalues larger than 1.0. This four-factor approach explains 42.6% of the variance. We assigned variables that load on two factors based on the analysis of the lateral load or for content reasons to the appropriate factor. Since a factor should have at least four variables with a sufficiently high factor load, we can now present a two-factor solution with the following thematic structure: Factor 1 = scientific integrity (Table 6.2) and Factor 2 = generic trust in science and scientists (Table 6.3). The translation of the items into the German language was done independently by three experts. In addition, three teachers validated the instrument to ensure that it is suitable for students. They evaluated the translated items in terms of wording and complexity in order to adapt them to the knowledge and experience of secondary school students.

The items for both factors demonstrated sufficient internal consistency to warrant merging them into a scale each (scientific integrity: $\alpha = .70$; generic trust scientists: $\alpha = .82$). We decided to use Factor 2 in order to investigate the general trust in scientists and science and to enable a more practical use of the instrument on students. For practical reasons we call this scale *trust in science* or just *trust* in the following.

We piloted the adapted instrument with a group of $N = 44$ students from three different classes of Grade 13 (mean age = 18.76 ($SD = 0.91$)). The students carried out the interventions as planned and were asked to discuss incomprehensible aspects of the questionnaires in an open plenary session. This collaborative validation enabled us to eliminate ambiguities in formulation and technical terminology. We could find sufficiently high internal consistency (Cronbach's α pre-test = .744; Cronbach's α post-test = .865) for the new 5-item scale.

Table 6.2. Compilation of the variables of Factor 1: scientific integrity

Variable	Item	Load
19	We cannot trust scientists to consider ideas that contradict their own.*	.649
17	We cannot trust scientists because they are biased in their perspectives.*	.597
2	Scientists ignore evidence that contradicts their work.*	.577
18	Scientist will protect each other even when they are wrong.*	.565
6	Scientists don't value the ideas of others.*	.535
20	Today's scientists will sacrifice the well being of others to advance their research.*	.501
4	Scientists intentionally keep their work secret.*	.423
8	Scientists don't care if laypersons understand their work.*	.348

Table 6.3. Compilation of the variables of Factor 2: generic trust in science and scientists

Variable	Item	Load
10	We should trust that scientists are being honest in their work.	.903
11	We should trust that scientists are being ethical in their work.	.840
9	We should trust the work of scientists.	.751
7	I trust that the work of scientists to make life better for people.	.395
12	Scientific theories are trustworthy.	.344

6.4.2 RF 2: Students' Level of Trust in Science

A sufficiently high internal consistency could be determined for both studies (Cronbach's α Study I = .742; Cronbach's α Study II = .740). The pre-test results indicated that students had a rather high overall trust in science ($M_{\text{StudyI}} = 3.51$ ($SD = 0.60$); $M_{\text{StudyII}} = 3.48$ ($SD = 0.63$); five-point Likert scale). The independent variables of socio-demographic information did not affect the level of trust in science significantly. Thus, no difference in the level of trust could be found in terms of gender, or chosen subject focus. Furthermore, there was no correlation between trust and the age of the

students nor with their grade. We could only find a weak correlation for trust in science and marks in science subjects as well as for trust in science and individual interest in biology and chemistry (Table 6.6 and 6.7).

6.4.3 RF 3: Effects of Outreach Activities on Trust in Science

The mean value comparison of the pre- and post-test results for trust in science and scientists showed no significant differences for both studies (Table 6.4). Additional analysis of Repeated Measures *ANOVAs* showed that neither was there a change in trust depending on gender, subject focus, age, grade nor in science marks for both studies.

Table 6.4. Mean values (standard derivation) for trust in the science of pre- and post-test for both studies and the corresponding statistical values of the *t*-tests

Study	Pre-test Mean (SD)	Post-test Mean (SD)	df	<i>t</i>	<i>p</i>
I	3.52 (0.60)	3.51 (0.64)	416	.190	.849
II	3.48 (0.63)	3.51 (0.66)	332	-1.036	.301

We further dichotomized high and low levels of trust in science and scientists. These levels were operationalized as one standard deviation above (high-trustors) or below (low-trustors) the mean of the pre-test scores (+1SD/-1SD). The statistical division of the groups resulted for Study I in 63 high-trustors and 55 low-trustors and for Study II in 61 high-trustors and 39 low-trustors. An analysis of variance with repeated measurements showed that the change of the trust level is related to the pre-level of trust ($F_{\text{Study I}}(1,110) = 21.543, p < .001, \text{partial } \eta^2 = .164, f = 0.44$; $F_{\text{Study II}}(1,97) = 39.894, p < .0001, \text{partial } \eta^2 = .291, f = 0.64$). Thus, low-trustors were able to gain significantly more trust in science through outreach activities compared to high-trustors (Figure 6.2 and Figure 6.3). According to Cohen (1988) the effect size *f* each corresponds to a strong effect.

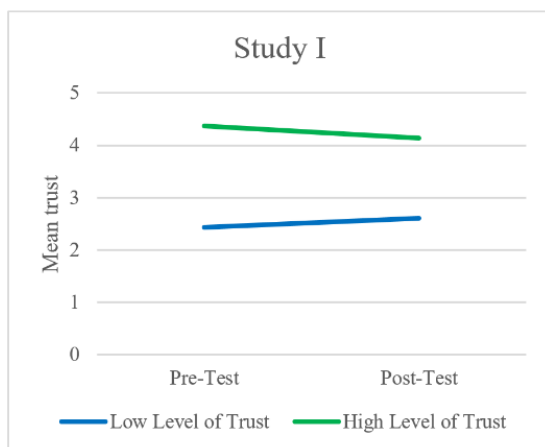


Figure 6.2. Change of mean trust in science through the outreach activity according to different pre-levels of trust in science for Study I

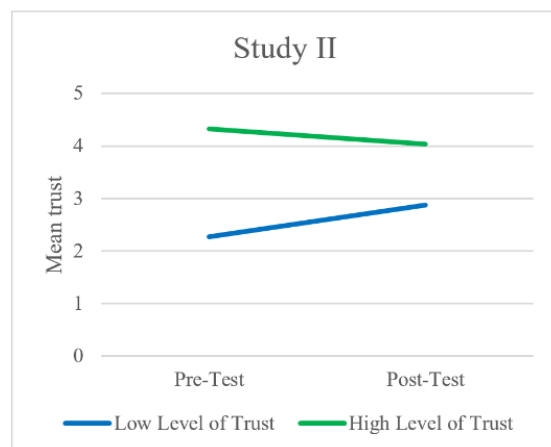


Figure 6.3. Change of mean trust in science through the outreach activity according to different pre-levels of trust in science for Study II

6.4.4 RF 4: Relationship Between Learning Success and Trust in Science

The level of trust in science had an influence on the level of learning achievement through the outreach activity ($F(1, 438) = 12.647, p < .001, f = 0.16$). However, only 2.6% of the variation in learning achievement was explained by the level of trust in science. The effect strength $f = 0.16$ represents according to (Cohen, 1988) only a low effect.

In both studies, students with a high level of trust in science learned significantly more through the outreach activities than students with a low level of trust in science (Table 6.5). The effect sizes according to (Cohen, 1988) showed a medium effect for Study I and a strong effect for Study II.

Table 6.5. Differences of knowledge achievement between high and low levels of trust: Means and standard derivations of knowledge test scores and statistical values of performed *t*-tests

	High trust Mean scores (SD)	Low trust Mean scores (SD)	df	<i>t</i>	<i>p</i>	<i>d</i>
Study I	9.3 (2.44)	8.0 (3.77)	116	2.253	.026	0.42
Study II	13.89 (4.50)	10.49 (3.52)	98	3.998	< .001	0.82

6.4.5 RF 5: Effects of Experiments and Computer Simulation on Trust in Science

Results showed that students in Study I had a significantly higher level of trust in science after working on the simulation than after working on the experiments ($t(419) = 2.299, p = .022, d = 0.22$), although there was no difference in the pre-test results ($p > .05$). For Study II we did not find a difference between the two groups ($p > .05$). The order of the methods thus had no impact on the development of trust in science.

6.5 DISCUSSION

6.5.1 Adapted Instrument Can be Used With Secondary School Students

Following Nadelson et al. (2014) who recommended the vetting and adaption of their instrument for use with school students we first developed and validated a short scale for the use with students. We now can assume that the new short scale of the TSSI can indeed be used with German secondary school students due to its reliable results. However, the already initially high mean values could also indicate a ceiling effect. It would be interesting to examine younger students, e.g., from the middle school. In addition, the development of further differentiated methods is advisable.

6.5.2 Secondary School Students Had a Rather High Level of Trust in Science

The mean value of trust in science of the school students is very similar to the mean value of university students (Koehler & Pennycook, 2019; Nadelson et al., 2014; Nadelson & Hardy, 2015). Even though the latter is a group that has chosen to study science and could therefore have been expected to have a higher level of trust in science. This suggests that trust in science is already

successfully developed to a certain degree during school education at least in this cohort of secondary schools.

The non-existent correlations of age or grades with trust indicate that trust may have been already developed before students entered secondary school. It would be interesting for further research to look longitudinally to examine changes during the school career and cross-sectionally through all levels of the school system to see if there is a development of trust during the school career (comparable to Kuhn, Cheney, and Weinstock (2000) and Hofer and Pintrich (1997), who describe such a development of epistemic sophistication). It would also be interesting to investigate which factors have a promoting effect on the development of trust during the school years.

The correlation between individual interest, understanding of science and trust might indicate that not only the understanding of science practice is important to promote trust in science, but also the interest in it. This seems to be especially relevant for educators and should be considered for the design of outreach activities. However, these considerations are very limited because the correlation between interest and trust is very weak. Further research to better understand this correlation is therefore required.

6.5.3 Trust-Enhancing Effect of Outreach Activities Only for Low-Trustors Verifiable

The fact that we did not find general changes in the trust level due to the outreach activities is consistent with recent research (Kingsley et al., 2017; Ocobock & Hawley, 2020). Several causes could serve as explanations: Firstly, the already relatively high mean pre-test values of the participants could have led to ceiling effects. This means that the level of trust could not be increased much further. Secondly, general trust in science seems to be a relatively permanent predisposition, which might be unaffected especially by such short-term interventions. In order to investigate the influence of such activities on trust in science, additional instruments with a more specific focus may be necessary.

However, we could identify a positive influence of the outreach activities on low-trustors. Science-based outreach activities, therefore, might be useful with the intention of reducing negative societal tendencies, which are supported by a low level of trust (science denialism, conspiracy theories, etc., see Section 6.2). Of course, this observation only applies to our interventions, which are designed very closely to science. Further science-based outreach activities (e.g. in interdisciplinary student laboratories) should be evaluated to test whether the results are reproducible.

6.5.4 Trust in Science Positively Influences Learning Achievement

Although the learning achievement could only be predicted to a limited extent by general trust in science, the dichotomous subdivision of the construct showed that a high level of trust seemed to facilitate learning of science-related topics in outreach activities. This assumption is also supported

by the fact that, at least to a small extent, a high level of trust correlates with good marks in science subjects.

We could not find similar research results in this area yet, but evidence from other fields of research allows comparable conclusions. For example, research in the field of business and economics shows that interpersonal and organizational trust have a positive impact on organizational learning (Attiq, Rasool, & Iqbal, 2017; Jiang & Chen, 2017). Research on education and development indicates a positive influence of interpersonal trust between co-learners on the learning process (Anwar & Greer, 2012; Brücknerová & Novotný, 2017; Klijn, Edelenbos, & Steijn, 2010). In addition, Durkin and Shafto (2016) identified epistemic trust as a mutable factor that influences learning in an academic setting. This means that the trustworthiness of informants (teachers, professors, etc.) positively influences the learning success (Koenig & Harris, 2005; Lee & Kim, 2016; Pasquini, Corriveau, Koenig, & Harris, 2007; Schlesinger, Flynn, & Richert, 2016). Thus, trust in science should already be encouraged in school to support the learning of scientific principles and processes. A high level of trust might encourage learning and motivation for science activities rather than questioning the trustworthiness of science. This is followed by Elby and Hammer (2001) who stated in the context of epistemic beliefs that for learning physics, absolute thinking ("Knowledge is absolute and certain") might be a better precondition for achievement than multiplicistic thinking ("Knowledge is tentative and uncertain").

As deduced in the introduction, a high level of understanding of science leads to greater trust in scientific processes and findings. According to our findings, the higher level of trust might in turn also promote the understanding of scientific findings. However, since the trust level correlates with prior knowledge and interest in biology and chemistry, the causality cannot be explained definitively here. The learning success could therefore also be a result of the higher interest or the cognitive abilities, demonstrated by the prior knowledge. This confounding effect limits these statements and requires further research on these dependencies. Nevertheless, educators can use this interdependency as a self-enhancing effect to promote scientific literacy.

6.5.5 Computer Simulation as Learning Method May Promote Trust in Science More Than Experiments

The closer consideration of the learning methods of our outreach activities showed that different methods might have an impact on the development of trust. Both methods were developed on the basis of the same scientific findings. However, it seems that the more open character of the hands-on experiments has led to less trust in science among students than a digital computer simulation. Students may have realized the vulnerability to failures and the subjective dependency of experiments. Moreover, experiments only represent one specific process. Therefore, students may have more trust in simulations based on the results of many experiments. These findings are of interest

for future developments of outreach activities. Hands-on experiments represent a typical learning method of Science Education (NRC, 2012; NSTA, 2013). Computer simulations also become increasingly important in science teaching, especially in subjects such as chemistry, biology, or physics (Rutten et al., 2012). Science educators or communicators are often faced with the question of which methods they can use to convey their goals. Our results may help with such decisions.

6.5.6 Limitations

A theoretical limitation is that the presented results only apply to our interventions. Further research on students' trust in science is thus required to test the replicability of the results. Furthermore, the selection of participants may have influenced the level of trust in science: The participants of our studies had a rather high educational level, as all of them aspired to the highest level of school graduation in Germany (Abitur). In general, all teachers from North German secondary schools could voluntarily register their classes from Grade 10 to 13 for the outreach activities. However, it is likely that more engaged teachers with an understanding of or interest in science registered their class for the outreach activities. The students may therefore have already had a more scientific background. In addition, the students had quite good marks in science and a high level of interest in biology and chemistry, which may have influenced the high level of trust also. However, the studies conducted with the TSSI so far have also been conducted with highly educated participants (Kingsley et al., 2017; Plohl & Musil, 2020; Slater et al., 2019; Szczuka et al., 2020), so the limitation in terms of comparability of results is considered to be low. Students with a high level of trust in science had better marks in the science subjects. Therefore, the finding that a higher level of trust in science has a positive effect on the learning success of the outreach activity may be reasonably questioned. It may also be that the students with better marks generally had a learning advantage and therefore learned more through the intervention. Further research is required to examine this aspect in detail.

6.5.7 Outlook

This paper presents an example of the great potential of transferring classical research interests in science communication to the research field of science education (Baram-Tsabari & Osborne, 2015). We conclude that students in our cohort of secondary schools had a fairly high level of trust in science. Accordingly, trust may have already been developed during the previous school years. For further research, it is therefore of interest to investigate which factors have a beneficial effect on the development of trust. In addition, we call for an investigation of the replicability of the results with other outreach activities. Even if the results do not point to a lack of trust in science, the further promotion of trust in science through authentic learning environments such as outreach activities in student laboratories is of great importance. Increasing informed trust, especially among students with low levels of trust in science, can thus counteract negative social trends and avoid unwarranted beliefs.

6.6 APPENDIX

Table 6.6. Statistical values of t-tests for differences between the trust in science and gender (A = male; B = female participants) as well as the choice of subject focus (A = science-related or B = non science-related) for both studies (I + II).

Variable	Mean A (SD)	Mean B (SD)	df	t	p
Gender Study I	3.53 (0.54)	3.49 (0.67)	436	0.771	.441
Gender Study II	3.44 (0.66)	3.53 (0.55)	355	-1.475	.141
Subject focus Study I	3.50 (0.63)	3.52 (0.57)	432	-0.255	.799
Subject focus Study II	3.49 (0.69)	3.44 (0.56)	364	0.705	.481

Table 6.7. Statistical values of correlations between trust in science and different socio-demographic variables for both studies (I + II), significant correlations are highlighted in bold

Variable	r	p
Age Study I	-.064	.182
Age Study II	-.089	.089
Grade Study I	-.068	.154
Grade Study II	-.084	.110
Marks Study I	.101	.039
Marks Study II	.116	.027
Interest Study I	.218	< .001
Interest Study II	.231	< .001

7 FURTHER RESULTS

In addition to the results reported in the manuscripts, further variables were collected in Study II. These findings are important for a final discussion of this doctoral thesis. In the following section, therefore the additional methods are described, their results are presented and discussed in the context of the overall work. The statistical analyses were conducted using the statistical program IBM SPSS Statistics 23 on the methodological basis of Field (2013).

7.1 USE OF HANDS-ON AND DIGITAL METHODS IN SCIENCE CLASSES

7.1.1 Introduction

The use of hands-on experiments as well as computer simulations in science education has shown positive educational effects (Hofstein & Lunetta, 2004; Rutten et al., 2012). However, German schoolchildren are often criticized for a lack of competencies, particularly in dealing with digital media (Eickelmann et al., 2019). Students might practice using these media too rarely, maybe due to the inadequate digital infrastructure (OECD, 2020) or a possible lack of teacher skills (Lorenz et al., 2017). Adapted from the BITKOM study on the use of digital media by children and young people (BITKOM, 2015), questions were developed to investigate the frequency of use of hands-on and digital media in the science classes of the sample. The research focus was on the evaluation of (I) the use of general media in science classes, and (II) the use of experiments and simulations as learning methods, as well as (III) the implementation of an independent variable for the learning success and the cognitive load through the methods. Since hands-on experiments are a widely used and well-known method in science education, digital simulations were expected to be less common in science classes. On the one hand, students who are used to working with digital methods were expected to better understand the nonlinear and complex structure of the simulation and thus have a higher learning success as well as a lower cognitive load. On the other hand, students who are trained to experiment would be able to grasp the experimental setup and workflow better, allowing them to learn more through the experiments besides lower cognitive load.

7.1.2 Method

In the first section, the students were asked about the general use of digital media, in the second section about the use of experiments and digital methods in more detail. For the differences between animations and simulations, see Manuscript I, Introduction.

The questions used were the following:

1. *How often are digital media (office applications, tablets, computer simulations, etc.) used in your science classes?*
2. *How often are the following methods used in your science classes?*
 - a. *Experiments, demonstrated by the teacher*
 - b. *Experiments, carried out by students themselves*
 - c. *Computer animations*
 - d. *Interactive computer simulations*

Students had to answer each item of Question 1 and Question 2 on a 5-point Likert scale: 1 = never; 2 = rarely (less than once a month); 3 = occasionally (once a month); 4 = often (once a week); 5 = very often (more than once a week).

The questions were checked for comprehensibility and correctness with the same participants of the pilot study as described in Manuscript II. Afterward the questionnaire was implemented in Study II with $N = 367$ valid participants from Grade 10 to Grade 13. To check for general differences, students were also asked about the type of school they attended and their chosen subject focus. Almost two thirds (72.2%) of the participants attended a Gymnasium and one third (27.8%) a Gemeinschaftsschule. At German schools, it is typical for secondary school students to choose a subject focus. About half of the participants (54.8%) chose science-related courses (biology, chemistry, physics, science) and the other half (45.2%) chose non-science related courses (arts, economics, sports, languages, social studies).

7.1.3 Results

(I) The results showed that 54.5% of the participants used digital media only up to once a month (Figure 7.1).

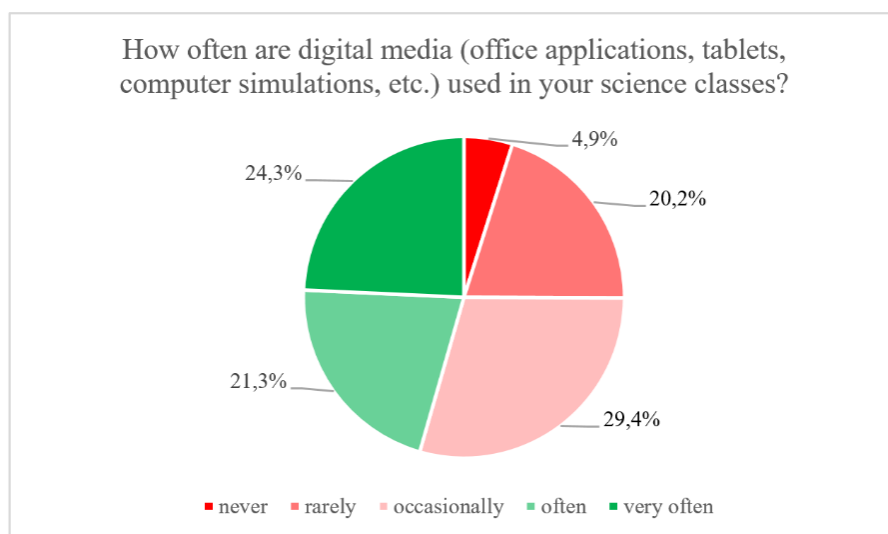


Figure 7.1. Use of general digital media in science classes; frequency of use indicated in percent (never; rarely = less than once a month; occasionally = once a month; often = once a week; very often = more than once a week).

(II) Focusing the use of the specific methods (Figure 7.2), the results showed that experiments carried out by students themselves ($M = 2.87$; $SD = 0.83$) or demonstrated by the teacher ($M = 2.75$; $SD = 0.87$) as well as computer animations ($M = 2.62$; $SD = 1.14$) were used almost once a month. Only interactive computer simulations were used more rarely ($M = 1.86$; $SD = 1.01$).

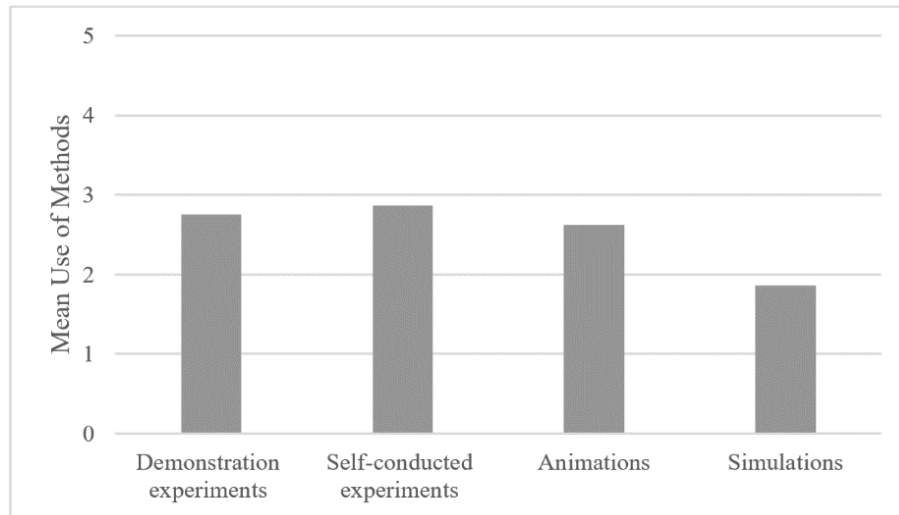


Figure 7.2. Use of hands-on / digital media in science classes (1 = never; 2 = rarely (less than once a month); 3 = occasionally (once a month); 4 = often (once a week); 5 = very often (more than once a week))

The analysis of socio-demographic variables revealed significant differences in the use of the media depending on school type and subject focus. Thus, general digital media as well as animations and simulations were used significantly more often at Gymnasien than at Gemeinschaftsschulen (Table 7.1). The experiments were conducted with equal frequency in both types of schools. Students with science-related subject focus reported significantly more experiments carried out by themselves as well as experiments demonstrated by the teacher than students with non-science-related subject focus (Table 7.2). There was no difference in the use of digital learning media between the chosen subject focuses.

Table 7.1. Mean (standard derivation) of the use of digital media in science lessons for different types of school as well as statistical values for the t -tests (Gym. = Gymnasium, Gem. = Gemeinschaftsschule)

Media use	$M (SD)$ Gym.	$M (SD)$ Gem.	df	t	p	d
General digital media	3.50 (1.12)	3.14 (1.34)	365	2.614	0.009	0.31
Animations	2.79 (1.11)	2.17 (1.10)	363	4.776	< 0.001	0.56
Simulations	1.97 (1.03)	1.57 (0.90)	364	3.456	0.001	0.40

Table 7.2. Mean (standard derivation) of the use of experiments (demonstrated or self-conducted) in science lessons for different subject focus as well as statistical values for the t -tests

Media use	$M (SD)$ Science focus	$M (SD)$ Non-science focus	df	t	p	d
Demonstration exp.	2.97 (0.84)	2.49 (0.83)	365	5.429	< 0.001	0.57
Self-conducted exp.	3.08 (0.81)	2.62 (0.79)	364	5.506	< 0.001	0.58

(III) The analysis of the regressions showed no significant influence of the general use of digital media in class on learning success or cognitive load when working with the simulation (all $p > 0.05$). In addition, there was no significant influence of the implementation of experiments in science classes on the learning success or cognitive load when working on experiments (all $p > 0.05$).

7.1.4 Discussion & Conclusion

(I) The prevalence of digital media in science classes suggested that the frequency of use could still be increased. A self-assessment of teachers in a survey conducted by the Gewerkschaft für Erziehung und Wissenschaft (GEW, 2020) on the demand for digital infrastructure and training in German schools showed that more than half of the teachers used digital media such as projectors, smartboards, computers, and tablets several times a week. However, only almost a quarter of the school students surveyed in the study stated that they use digital media in science lessons at least once a week. The reasons for these different statements can be manifold: For example, falsified answers due to social desirability of the teachers, unrepresentative sample of the GEW survey, differences in the subjects, or incorrect assessments by the students could serve as explanations. Regardless of the reasons for the different findings, the use of digital media in the classroom should be further promoted. A weekly if not daily use of digital media seems to be obligatory in order to fulfill the educational mission of the schools: Preparing students for a life in a digital world (Kultusministerkonferenz, 2017). To take full advantage of the potential of digital media, possible concerns of teachers should be reduced and digital competencies should be promoted, e.g. through teacher training or through enhanced use of digital media in university teacher education. Also, the digital equipment in schools should be improved (Bundesministerium für Bildung und Forschung, 2020).

(II) The rare use of interactive computer simulations in classrooms is probably due to the high effort for their adequate implementation in science lessons. The use of a simulation requires good technical equipment (hardware and solid internet connection) as well as digital competencies of the teachers to instruct a simulation and to develop a suitable learning environment. Often this means an enormous additional effort for the teachers and results in low usage (GEW, 2020). In order to keep the above-mentioned demands on the educators low, didactically well-prepared simulations that are well adapted to the students' requirements are necessary. However, such adequate simulations for classroom content are still not widespread enough. However, interactive computer simulations in particular offer high potential for learning content knowledge and provide the opportunity for authentic communication of modern science (Rutten et al., 2012). Therefore, the development of adequate simulations for classroom content should be further promoted.

The more frequent use of digital methods at Gymnasien compared to Gemeinschaftsschulen may be due to significant differences in the students' academic performance (Ministerium für Bildung,

Wissenschaft und Kultur des Landes Schleswig-Holstein, 2020; Reiss, Weis, Klieme, & Köller, 2018), different skills of the teachers or fundamental differences in the digital equipment of the schools.

The expected increased use of experiments in science classes with science-related subject focus reflects the fundamental differences of science lessons with different subject focuses. First, science classes for students who have chosen a science-related subject focus especially aim at conveying scientific inquiry and scientific literacy. Therefore, the implementation of experiments to gain insights into the scientific knowledge acquisition and scientific work is essential. Second, teachers for science classes with science-related subject focus have more lessons available than for science classes with non-science-related subject focus. The use of experiments is often associated with an increased time investment and therefore is often not viable for teachers if less lessons are available.

(III) Contrary to the assumption, students who were already familiar with certain methods did not have an advantage when working with these methods in terms of learning success or cognitive load. The didactically well-prepared methods, including the instructional support, presumably enabled learning with the methods regardless of the students' preconditions.

In conclusion, the use of digital media in science lessons (especially interactive computer simulations) should be further promoted. Gemeinschaftsschulen have a particular need to catch up on this aspect. On the one hand, more adequate and didactically well-prepared digital offerings should be created for this purpose. On the other hand, the digital infrastructure in schools as well as the teachers' media competencies should be improved. Especially out-of-school learning locations such as student laboratories are ideal for implementing digital media due to their high level of equipment. Therefore, further offers like the ones presented in this doctoral thesis should be promoted.

7.2 MEASUREMENT OF THE CREDIBILITY OF METHODS

7.2.1 Introduction

One of the goals of the outreach activities developed in this doctoral thesis was to give the participants an authentic insight into modern science (Section 2.3.1). For this purpose, experiments and a computer simulation were developed in close collaboration with marine ecologists (see Manuscript II). On the one hand, these methods should serve as a learning method (conveying science literacy) and, on the other hand, as an example of a scientific method (conveying scientific inquiry). Did the students, therefore, trust the methods used to be authentically scientific methods? In other words, how high was their level of credibility?

To answer this question the results reported in Manuscript III provide an indication: Working on a simulation might promote more trust in science and scientist as working on experiments does. However, this investigation of trust in science is rather general and the effects of the methods can only be assumed indirectly. Therefore, an explicit investigation of the credibility of the used methods was intended. Since no suitable instrument for this purpose existed so far, a new questionnaire was developed and subsequently applied in Study II. The following research questions guided the evaluation:

(I) What level of credibility do the students have in the different methods (experiments or simulation)?

(II) Do differences exist concerning the subscales expertise, actuality, certainty, and intention?

7.2.2 Method

The development and validation of the instrument to measure the credibility of methods occurred in three phases (see Figure 7.3): (1) Identification of overarching concepts and item development based on a literature review, (2) item validation by expert researchers and a pilot-study, (3) the implementation of the questionnaire in Study II with following explorative & confirmatory data analysis. Each of these phases are described in more detail below.

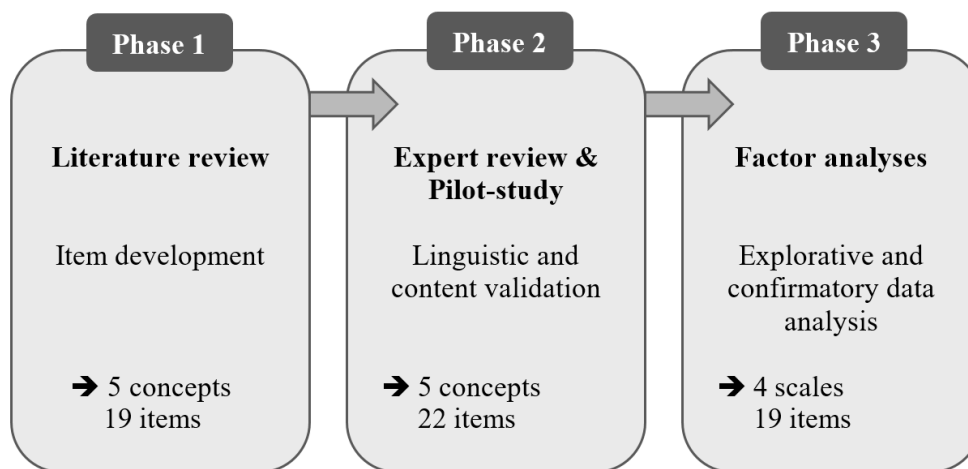


Figure 7.3. Phases of the development of an instrument to evaluate the credibility of learning methods

The instrument was implemented in Study II in both the intermediate and post-test. After successful factor analyses, the data was used for the substantive investigation of the credibility of the used methods.

Phase 1: Literature-Based Item Development

Assessments of credibility in online learning environments and general media use were analyzed as well as evaluations of the perceptions of online information credibility (Banning & Sweetser, 2007; Flanagin & Metzger, 2008; Flanagin, Metzger, & Hartsell, 2010; Metzger, 2007; Metzger,

Flanagin, & Zwarun, 2003; Sundin & Francke, 2009). This resulted in five overarching categories: Actuality, certainty, completeness, authority/expertise, and intention of the methods (Aktualität, Sicherheit, Vollständigkeit, Autorität/Expertise, Intention). Especially the research of Flanagin et al. (2010) and Flanagin and Metzger (2008) on digital media use and information credibility of youths served as a basis for the following development of items for each of the above-mentioned categories. Subsequently, 19 items were developed and validated in Phase 2.

Phase 2: Validation

For a first content validation, four experts from the educational sciences were consulted. They covered various areas of expertise, such as research on nature of science, educational psychology, and science communication, as well as general questionnaire development. They were asked to firstly evaluate the sufficiency of the overarching categories and secondly to check the corresponding items on a linguistic and content level. The experts found the categories to be sufficient. The experts added three items for the sake of completeness. Afterwards, a pilot study was conducted with $N = 44$ students from Grades 10-13 (for a more detailed description, see Manuscript I and Manuscript II). In this study, the students carried out the student lab day as planned. Afterwards they were asked to discuss incomprehensible aspects of the questionnaire in an open plenary session. This collaborative validation enabled us to eliminate ambiguities in the formulation and technical terminology.

Phase 3: Factor Analyses

The aim of the factor analyses was to represent the 22-item variable set by a few independent factors with statistical and content-related justification. For this, the structure of the instrument was analyzed using explorative and confirmatory factor analysis with the data from the intermediate- and the post-test of Study II. For a detailed description of the intervention of Study II and the participants, see Manuscript I and Manuscript II.

Both the Bartlett-test ($\text{Chi-square}(231) = 4569.712, p < .001$) and the Kaiser-Meyer-Olkin Measure of Sampling Adequacy ($\text{KMO} = .890$) indicated that the variables were suitable for factor analysis. The main component analysis with varimax rotation indicated four factors with eigenvalues larger than 1.0. This four-factor approach explains 49.65% of the variance. Based on the analysis of the lateral load or for content reasons variables that load on two factors were assigned to the appropriate factor. In this process three items had to be deleted. The exploratory factor analysis finally suggested four underlying factors with 19 items which was also confirmed by confirmatory factor analysis. Additionally, the internal consistency (Cronbach's alpha) was sufficiently high for both test times (Table 7.3).

7. Further Results

Table 7.3. Resulting scales after explorative and confirmatory factor analysis and corresponding internal consistency (Cronbach's α) for both test times of Study II; Items here in German, because they were validated this way

Scales	Items	α interm.	α post
Expertise		.575	.726
	Experten dieses Themengebietes vertrauen den Ergebnissen der Experimente/Simulation.		
	Die Experimente/Simulation wurden von Wissenschaftlerinnen und Wissenschaftlern entwickelt.		
	Die Experimente/Simulation liegen wissenschaftlichen Erkenntnissen zugrunde.		
	Die Erkenntnisse auf denen die Experimente/Simulation aufbauen, stammen von Experten dieses Themengebietes.		
Actuality		.684	.786
	Die Erkenntnisse, die ich aus den Experimenten/Simulation gewinnen konnte, entsprechen dem neusten Stand der Forschung.		
	Die Ergebnisse der Experimente/Simulation sind aktuell.		
	Durch die Bearbeitung der Experimente/Simulation habe ich einen Einblick in aktuelle Forschungsergebnisse bekommen.		
	Durch die Bearbeitung der Experimente/Simulation konnte ich ein umfassendes Bild über die zukünftigen Veränderungen der Ostsee erlangen.		
Certainty		.729	.747
	Die Erkenntnisse, die ich aus den Experimenten/Simulation gewinnen konnte, sind vollständig.		
	Die Ergebnisse der Experimente/Simulation sind zuverlässig.		
	Die Erkenntnisse auf denen die Experimente/Simulation beruhen, stammen von einer vertrauenswürdigen Quelle.		
	Die Ergebnisse der Experimente/Simulation kann man wissenschaftlich nicht anzweifeln.		
	Die Ergebnisse von Experimenten/Simulation sind immer richtig.		
	Ich vertraue den Ergebnissen, die ich mithilfe der Experimente/Simulation erarbeitet habe.		
	Ich kann mich auf die Ergebnisse aus den Experimenten/Simulation verlassen.		
Intention		.593	.732
	In den Experimenten/Simulation wird nur eine bestimmte Sicht von Wissenschaftlern dargestellt.*		
	Das Ziel der Experimente/Simulation ist es, eine bestimmte Meinung zu transportieren.*		
	Durch die Erkenntnisse aus den Experimenten/Simulation soll meine politische Einstellung beeinflusst werden.*		
	Die Erkenntnisse, die man durch die Experimente/Simulation gewinnt, sind nur subjektive Meinungen.*		

7.2.3 Results

(I) The descriptive statistics show that the students rated the methods as highly credible ($M = 2.96$, $SD = 0.32$). The calculations of the t -test showed that the students had significantly higher credibility in the simulation than in the experiments ($t(695) = 2.495$, $p = .013$, $d = 0.19$). According to Cohen (1988) this represents a small effect.

(II) The results further showed no significant differences in the credibility of the methods between the subscales expertise, actuality, certainty, and intention.

7.2.4 Discussion & Conclusion

It can be assumed that there would be no transfer effects between the test times because the items were directly related to working with the different methods (see also the considerations on situational interest in Manuscript II). Consequently, the calculations could be carried out for each method individually, regardless of the test times. Since each student worked on two methods and assessed the credibility of each method, $N = 696$ test results were obtained.

(I) In the introductory lecture of the student lab day the students were introduced to the development process of the learning methods. This means that the students were aware that both learning methods based on the same scientific knowledge and were developed in close cooperation with marine ecologists. The generally high level of credibility of the methods meets the expectations but may also have been positively influenced by the information provided in the introductory lecture. The higher level of credibility of the simulation compared to the experiments can probably be explained by the arguments already presented in Manuscript III. Accordingly, the more open character of the experiments probably has lead to a lower level of credibility than the simulation. Since the results of experiments are not predetermined, the students may have realized the vulnerability to failures and the subjective dependency of an experiment. In addition, they were well aware that the experiments were authentic, but still reconstructed for the students. Therefore, students may have more trust in simulations based on the results of many experiments and represent real science.

(II) No differences in the subscales indicate either that the credibility in terms of the perceived expertise, actuality, certainty, and intention of the method is equal or that the scales were not adequately defined.

In conclusion, experiments and simulations seem to be credible learning methods. Thus, the use of both methods (but especially a simulation) can contribute to providing an authentic insight into science in outreach activities. However, it is important to note that the methods have to be developed in a co-design in order to obtain optimal outcomes. The students should be informed about the development process of the methods in order to have a solid basis for their assessment of the credibility of the methods. A more differentiated investigation of the credibility of the different methods offers further need for research. In particular, the analysis of the reasons for the differences promises to be interesting.

7.3 MEASURING CONCEPTS ABOUT SCIENTIFIC PREDICTIONS

7.3.1 Introduction

The development of predictions using model-based simulations is of great importance in modern science (Wissenschaftsrat, 2014). For example, model-based predictions are used in meteorology for weather forecasting (Baldauf et al., 2011), or in climatology for calculating ice melting or global

warming (Neumann, 2010a), and in disaster prevention for predicting flood events, earthquakes, or tsunamis (Couvin et al., 2020). For such models, a large amount of data from observations and previous experiments is necessary. The development of model-based simulations is complex and is often not easy for learners to understand. However, students have to handle information from model-based simulations in their daily life. For active participation in today's society, it is thus necessary to be able to assess the credibility of such predictions. Therefore, understanding the complex interaction of experiments and simulations and the development of model-based predictions is a fundamental requirement. In order to promote this knowledge and to provide an authentic insight into modern science, the combination of experiments and simulation was used as learning methods in the student lab day.

Since there is evidence that concepts about the nature of science can particularly be changed by an explicit presentation of the issues, the development of the learning methods was presented in the introductory lecture. In the further course, the issue was no more explicitly addressed.

In order to investigate whether the use of two authentic scientific learning methods could influence students' conceptions of scientific predictions, the well-known instruments for investigating the concept of nature of science (Abd-El-Khalick, Lederman, Bell, & Schwartz, 2001; Allchin, 2011; McComas, 2002; Schwartz, Lederman, & Lederman, 2008) or epistemic beliefs (e.g. Conley, Pintrich, Vekiri, & Harrison, 2004) appeared not to be appropriate due to their broad orientation. Hence, two open questions were developed asking a) how scientific predictions can be made, and b) how the reliability of these statements can be increased. The questions were implemented both in the pre-test and in the post-test to investigate the changes caused by the student lab day.

7.3.2 Method

Based on the basic literature on the nature of science mentioned above, two questions about the students' concepts of scientific predictions were developed. Three experts (areas of expertise: nature of science, science communication, educational psychology) validated the questions regarding the content and expectable answers. In the second step of validation, the questions were discussed with students of the pilot study (see also Manuscript II). Subsequently, the questions could be adapted in terms of wording and phrasing so that the following questions were used for the evaluation in Study II:

1. *Ecosystems such as the Baltic Sea are changing due to anthropogenic influence. Describe how scientists can predict these changes.*
2. *Scientists are interested in making predictions about certain future changes. The further these forecasts reach into the future, the more uncertain they become. Describe what scientists have to do to improve the quality of predictions.*

7.3.3 Results

Based on the qualitative content analysis of Mayring (2008), categories from the given answers were created (Table 7.4).

Table 7.4. Answer categories from Question 1 and Question 2

Answer categories Question 1	Answer categories Question 2
Recording the current state	Improve quality
Identifying past developments	Increase quantity
Developing models	Develop and improve models

The students received one point each for the answer category mentioned. Three different persons analyzed the students' answers according to the answer categories. In case of inconsistent evaluations, the majority opinion was decisive. After assigning points, a mean value was calculated and mean value comparisons were used to calculate the changes caused by the intervention. Due to technical problems, a large loss of data had to be suffered. That is why only $N = 194$ answers could be analyzed here.

After working on the two learning methods, most of the answers were more profound and comprehensive than before. Students scored significantly higher on the post-test than on the pre-test ($t(193) = 3.458, p < .001, d = 0.50$). This represents a strong effect according to Cohen (1988). An impression of the answers for each question is shown in Tables 7.5 and Table 7.6.

Table 7.5. Example answers Question 1

Pre-Test	Post-Test
<i>“Durch Messungen, Studien, Daten Sammlungen”</i>	<i>“Durch Messungen und Experimente sowie Erkenntnisse und Beobachtungen aus der Vergangenheit Simulationen erstellen”</i>
<i>“Messwerte vergangener Jahre analysieren und mit den Ergebnissen die Zukunft berechnen”</i>	<i>“Durch Langzeitmessungen, Versuchsreihen und Experimente kann ein Modell erstellt werden, welches auch Möglichkeiten für die Zukunft beinhaltet”</i>
<i>“Durch Statistiken der letzten Jahre”</i>	<i>“Viele Daten sammeln (Z.B. durch Experimente und viele Messungen), vergleichen mit letzten Jahren und Simulationen erstellen”</i>

Table 7.6. Example answers Question 2

Pre-Test	Post-Test
<i>“Mehr Tests machen”</i>	<i>“Versuche öfter durchführen – Bessere Geräte entwickeln”</i>
<i>“Experimente verbessern”</i>	<i>“verschiedene Messmethoden, viele Messungen, Methoden immer verbessern”</i>
<i>“Mehrere Statistiken vergleichen und tiefer in die Materie eindringen. Ebenfalls verschiedene Vorgehensweisen testen”</i>	<i>“Verlängerung des Messzeitraums, Erkennung und Einbringung neuer Prozesse/Einflussfaktoren, genauere Messmethoden, größere Einbeziehung vergangener Ereignisse (bspw. “Überprüfung von Simulationen” anhand bereits geschehener Prozesse)”</i>

7.3.4 Discussion & Conclusion

It can be assumed that the goal of the student lab day, to improve the students' perception of scientific predictions (Section 2.3.1), could be achieved at least by a large part of the participants. The large effect size of the t -test underlines this. Thus, it can be concluded that even an implicit representation of scientific work can have a positive effect on the participants' attitudes.

This finding indicates only limited evidence because of the large amount of data loss, although the loss was random. Therefore, no further analysis was conducted. In addition, the findings are only transferable to other outreach activities in a limited way. The development process of the methods were presented at the beginning of the student lab day, which may have had an influence on the answers. For the design of further outreach activities with similar objectives, interdisciplinary collaboration and a transparent presentation of the development processes is recommended. Another limitation of the results is the procedure for determining the category system. Since the data presented here is only a secondary aspect of this doctoral thesis, a more complex but scientifically more sophisticated analysis was not carried out. A further review of the category system is therefore desirable.

8 DISCUSSION & OUTLOOK

The main objectives of education are 1) the development of appropriate knowledge and of competencies to prepare young people adequately for life in today's as well as future society and 2) enabling them to contribute to sustainable development of our world (Kultusministerkonferenz, 2005; UNESCO, 2016). To achieve this educational goal, one aspect is becoming increasingly important: The digital transformation of society. In this process, digital media and digital tools replace analog methods more and more in all areas of life. They do not only replace existing technologies but also open up new perspectives in all social, economic, and scientific contexts (Kultusministerkonferenz, 2017). For the education sector, digitization offers great opportunities. Using adequate methods can help to change teaching and learning in a way that promotes talents and human potentials on a more individual level than before. The improved opportunities for the development of differentiated learning methods will enable teaching content to be better adapted to the interests and the abilities of students. This structural change, described by the Conference of Ministers of Education and Cultural Affairs as the "Digital Revolution" (Kultusministerkonferenz, 2017), also requires a reorientation of the knowledge and the competencies to be taught:

"Of course, solid expert knowledge will always remain important. But the modern world no longer rewards us solely for what we know - Google already knows everything - but for what we can do with what we know ..." (Andreas Schleicher (2020), head of the Directorate for Education at the Organisation for Economic Cooperation and Development (OECD) and chief coordinator of the PISA studies)

As Schleicher (2020) indicates, interrelated and application-oriented knowledge, critical thinking, and being able to fully exploit the potential of new technologies will be increasingly important skills for students in the coming years. However, contemporary educational activities to creatively use the potential of new technologies are called upon in order to liberate learning from outdated conventions and to link knowledge in new and dynamic ways (Schleicher, 2020). These new requirements pose great challenges for the education sector. Teaching and learning formats as well as the structure of learning environments must be reconsidered and redesigned. Above all, this requires the provision of infrastructural, legal, and personnel resources (Bundesministerium für Bildung und Forschung, 2020).

This section first summarizes the key findings of this doctoral thesis and then identifies general limitations. With regard to the third goal defined in Section 1, theoretical and practical implications

for the design of modern outreach activities are then derived. Finally, further development and research perspectives are identified.

8.1 OVERALL DISCUSSION

The empirical goal of this doctoral thesis was to investigate the effects of hands-on experiments and interactive computer simulations in outreach activities to communicate the complex processes of anthropogenic influences on the Baltic Sea marine ecosystem. Research on science outreach activities is often located in the interface between science communication and science education. The transferability of aims and objectives of one research field to the other therefore often offers great potential (Baram-Tsabari & Osborne, 2015). This doctoral thesis presents an example of this, in which the three research foci combine both classical constructs of science education research (e.g., knowledge acquisition) and science communication (e.g., trust in science). The research questions of the empirical studies (Section 2.3.3) developed for this purpose have already been answered comprehensively by the manuscripts and further results. Therefore, they are not discussed in detail here, but the linked aspects under the respective research focus are highlighted.

8.1.1 Research Focus I: The Comparative Study of Cognitive and Motivational Effects of Science-Based Experiments and Computer Simulations

On the one hand, the comparative study of the methods showed higher learning achievement for students working on computer simulations than for those working on experiments. Students were able to achieve better learning outcomes through simulations, although they had higher cognitive load. The proven negative effects of increased cognitive load on learning success (Jong, 2010; Kal-yuga, 2007; Stull & Hegarty, 2016) were probably offset by the predominant advantages of the simulation. In this context, it can be stated that simulations offer a great suitability to communicate complex issues. The topics dealt with in these studies both conveyed basic and complex processes and concepts (structured into three levels of complexity). The content of the second intervention was generally more complex than the content of the first intervention. Results indicate that the more complex the subject matter was the greater was the learning advantage of simulations over experiments (Manuscript I & Manuscript II). This is in line with current research from Scheuring and Roth (2017) as well as Lichti and Roth (2018) who were able to show that computer simulations mainly promote complex thinking processes. Furthermore, Smetana and Bell (2012) compiled indications for the suitability of simulations to convey complex content in their detailed review. One of the most important aspects of minimizing the negative effects of cognitive load was probably appropriate instructional support. Especially for students with little prior knowledge – as those in the interventions of this doctoral thesis – the instructional support offered effective help for the successful acquisition of knowledge (Eckhardt, Urhahne, & Harms, 2018; Jong & van Joolingen, 1998; Mayer, 2004; Rutten, van Joolingen, & van der Veen, J. T., 2012). Moreover, the special suitability

of simulations for imparting knowledge can have other causes. Apparently, the credibility of simulations is slightly higher (Section 4) and they cause a little more trust in science (Manuscript III) than experiments do. Both factors could be conducive to knowledge acquisition because the trustworthiness of the informants has a positive influence on learning success (Koenig & Harris, 2005; Lee & Kim, 2016; Pasquini, Corriveau, Koenig, & Harris, 2007; Schlesinger, Flynn, & Richert, 2016). In this case, the learning methods represent the informants. The higher level of credibility of the simulation could therefore have had a positive influence on the students' learning success. Simulations thus seemed to have a positive influence on the communication of complex current topics, both directly through their didactic suitability and indirectly through their high potential of credibility.

On the other hand, working on experiments promoted more situational interest than computer simulations (Manuscript I & Manuscript II). Today's students belong to the digital natives and grow up with digital media as part of their daily lives. This is why they might be no longer easily impressed by the options which digital media offer, such as the possibility of self-determined interaction within the application or by working with the medium itself. Even if such digital media are not used very often in school teaching yet (Section 4.1), working with a digital medium no longer seems to have any special value or epistemic relevance for the students because they are used to it in their daily life. The "novelty" effect, which is often assumed by existing literature, no longer leads to an increased situational interest as it did perhaps a few years ago (Jain & Getis, 2003; Rutten et al., 2012). The question of whether the existing assumptions are still valid or whether they need to be reassessed in light of society's digital transformation were already discussed, especially in the first manuscript. On average, experiments are carried out not more often than once a month in science classes (Section 4.1). So students are familiar with working with experiments from time to time, but in contrast to digital media, the students are not familiar with experimental procedures from their everyday lives. The experiments, therefore, represent something not common and thus might have positive motivational effects. This confirms the research of Lin, Hong, and Chen (2013) who indicated a positive influence of activities that are novel or conspicuous on students' situational interest. Further aspects such as the potentially positive motivational effects of lower cognitive load or increased motivation based on the immersion in the activity have already been discussed in Manuscript I.

All these findings for Research Focus I could be observed regardless of the learning location (school versus student laboratory). This excludes the influence of, for example, out-of-school settings on the development of interest and results in a special reliability of the findings.

For successful and sustainable science education, the communication of knowledge content is just as important as the promotion of interest. Since the learning methods investigated here each promote one of these factors particularly well, a combined approach of both methods seems to be the right way to benefit most from the positive effects. This conclusion is in line with the research of Smetana and Bell (2012) as well as Lichti and Roth (2018) who indicated the combination of laboratory experiments and model-based simulations as a potentially powerful learning tool. In addition, de Jong, Linn, and Zacharia (2013) emphasized that a combination of digital and analog learning elements seems to enable a deeper and more nuanced understanding, especially when teaching complex issues. The paucity of studies on the effects of combined methods and especially the unclear effects of sequence motivated the second research focus.

8.1.2 Research Focus II: The Investigation of Cognitive and Motivational Effects of the Combination of Hands-On Experiments and Computer Simulations as Well as Sequence Effects

Once the clear advantages of a simulation for knowledge acquisition were identified, the question arose as to why educators – with the goal of knowledge acquisition – should have to spend the effort for additional experiments at all. However, findings showed that the combination of the two methods had an important advantage when teaching complex topics (Manuscript II): knowledge achievement of the first method had a positive influence on the knowledge achievement of the second method. These (positive) transfer effects represent an important learning advantage, especially when working on experiments before a simulation.

In this thesis, not only the effects of a random combination of the methods were investigated, but the different sequencing options were tested in comparison to each other. This allowed the following conclusions to be drawn about the optimal sequence. Experiments focused on conveying the effects of a single change on one organism and one societal impact. The students could thus probably understand the basic processes better than if everything was presented at once (as the simulation did). This underlines the suitability of the experiments for teaching basic knowledge in particular (Köck, 2018; Mönter & Hof, 2012). In order to understand complex processes and correlations, such as the effects of climate change on ecosystems, students must first acquire declarative knowledge about the various factors of the system. They are then able to transfer the knowledge into a broader context. It is more difficult to understand complex interactions if they do not have this basic knowledge. Therefore, students' achievement was higher when they first learned basic processes and then observed and understood the findings on a systematic level (1st experiments and 2nd simulation). This highlights the complementing suitability of experiments for computer simulations for learning complex issues. Smetana and Bell (2012) also emphasized that the effectiveness of computer simulations depends on the way they are used and that they are most effective when used complementary to other educational tools. It can be concluded that the additional effort for

educators to use a combination of methods in teaching complex socioscientific issues will be worthwhile.

In addition to this cognitive supplementary suitability, the combination of first experiments and second simulation seems to result in a higher overall situational interest than the other way round. Even if the effect was only slight, this sequence seems to be preferable. The higher knowledge achievement in the post-test of this group compared to a different sequence of methods could also be due to the learning-promoting factor of an increased situational interest in this group. Students should therefore work on the experiments before the simulation in order to ensure better learning also due to the resulting higher interest.

8.1.3 Research Focus III: Research on the Effects of Outreach Activities on Students' Beliefs Regarding Science

In addition to Research Focus I & Research Focus II, which explored the pedagogical effects of the methods, the third research focus considered at the overall effects of the outreach activities. One goal of the outreach activities was to provide an authentic insight into modern science through the interaction of experiments and simulations. This was aspired by improving the students' perceptions about the development of scientific predictions (Section 4). Indications suggest that the student lab day was successful in this regard, although the reliability of the results is limited due to the loss of data. The explicit presentation of the development of the learning methods may have promoted this.

As already stated in Manuscript III, neither total trust nor total distrust seems to bring students to a reflective attitude towards science to enable them to actively participate in modern science-based society. Therefore, for the success of the outreach activity, it is not important whether the overall level of trust has increased or not. It is rather important to increase the trust of students with a low level of basic trust. Concerning this goal, the outreach activities were successful.

As the results of the credibility study (Section 4) and Manuscript III showed, a simulation seemed to be (to a low degree) more credible and contributed more to general trust in science than experiments. However, it is unclear how these factors correlate. It is conceivable that the higher credibility of the method positively influenced the students' basic beliefs towards science. Further research is necessary to achieve this. However, to increase trust in science through outreach activities (especially among students with a low level of trust), the use of science-related simulations could be particularly advisable.


The generally high level of trust in science may have had an impact on the credibility of methods and the development of the perceptions about scientific predictions. Students who trust science to a high degree may also be more inclined to trust science-related methods. Because of the positive correlation between trust and learning, it is also conceivable that attitudes about scientific

knowledge acquisition – as in this case the development of predictions – may change to a more positive degree among students with a high level of basic trust. Future studies with students with low trust in science would be of interest here.

8.1.4 Summary

A summarizing overview of the results of this doctoral thesis is provided in Figure 8.1.

Table 8.1. Summarized results of the motivational and cognitive effects of experiments and simulations on students

Experiments	Simulation
<ul style="list-style-type: none"> + communicating basic knowledge + higher situational interest + lower cognitive load 	<ul style="list-style-type: none"> + communicating complex topics + higher credibility & trust - higher cognitive load
	
Combination 1 st Experiment + 2 nd Simulation	
<ul style="list-style-type: none"> + more knowledge achievement + higher situational interest + improving perceptions about scientific predictions + positive effects on development of trust in science 	

8.2 LIMITATIONS

In addition to the limitations already described in the manuscripts (Section 3) and further results (Section 4), the following considerations may limit the findings of this thesis.

When comparing the single with the combined use of the methods, the students worked on the topic for different durations. This time-on-task effect obviously ensures a higher learning success through the combination. For better empirical comparability, a control group that did the same method twice would have been desirable. However, this did not seem to make sense, neither for moral nor for practical reasons. Simply repeating the same activity is not valid holistically and would certainly lead to irritation and lower motivation among the students. Nevertheless, the increase in knowledge by combining the methods demonstrates the benefit of this approach even in spite of the lack of a control group. For further research in this area, the duration of the methods could be adjusted. Students who work on only one method could be given the entire time. In the combined approach, students could spend half the time working with experiments and half the time working with simulation. However, this approach was not possible in the study design of this doctoral thesis because the content level was too high. For this complex topic, it was not appropriate to shorten the working time of the individual methods to this extent.

Regarding the instruments' quality, it should be noted that in the case of the construct *trust in science*, ceiling effects occurred at the pre-test. Thus, possible effects – such as potential socioeconomic dependencies – remained undiscovered. Although these results reflect the high level of trust in science among senior school students, they also limit the interpretive power of the results to a certain extent. Here, further development of the instrument is recommended.

Furthermore, the interventions were designed to address the specific issue of ecological changes. Perhaps interactive simulations are particularly well suited to explain complex biological and chemical issues. The transferability to other socio-scientific issues should therefore be examined.

Unfortunately, a significant data loss in Study II due to technical problems occurred. Of the more than 500 participants (30 classes) at the student lab days, more than 150 data sets had to be abandoned because they were incomplete. However, no consequences were expected for most constructs because the data loss was random. Only the validity regarding the questions about scientific predictions is somewhat limited since the loss of data was particularly high here.

In general, a dependence of the students' answering behavior on the instructor could be questioned. The problem of social desirability when answering the questions (this applies especially to the constructs interest and trust) seems to be a fundamental problem of empirical social research and must be accepted here. Furthermore, the students' concentration when answering the (long) post-test questionnaires could have been affected by the long and exhausting day in the student laboratory. The real learning success could thus have been somewhat higher than shown in the reported results.

A frequent problem in social research is the selection of non-representative groups of participants. Efforts were made to minimize this problem as much as possible. Still, more participants attended the Gymnasium than the Gemeinschaftsschule (ratio of 2:1 between Gym. to Gem.), but the classes were distributed throughout Schleswig-Holstein (Study I: 7 x Kiel, 12 x Rendsburg-Eckernförde, 5 x further districts; Study II: 17 x Kiel, 3 x Rendsburg-Eckernförde, 9 x further districts). However, the teachers initiated the registration of the classes for the outreach activities. This means that classes with engaged science teachers may have been more likely to participate in the interventions. Since the quality of education depends on the teacher (Hattie, 2012), it can be assumed that the participants were rather well qualified. On the one hand, this leads to a limitation of the generalizability of the results. On the other hand, exactly the target group that typically participates in scientific student lab days was surveyed.

8.3 IMPLICATIONS

Theoretical and practical implications that can be derived from the discussed results of this doctoral thesis are explained on the basis of the offer/take-up-model (Angebots-Nutzungs-Modell, Helmke (2012)). The adapted offer/take-up-model (Figure 8.1) describes a framework for the design and

evaluation of outreach activities. The central point is that the use of the activities on the side of the participants as well as on the side of the communicators is influenced by their preconditions and perceptions of the activity. In contrast to the original model, the use and effects of the activities are not only considered on the side of the participants/learners but also on the side of the communicators. The investigations of this doctoral thesis gave indications about the effects of the participants as well as information about some preconditions (see Table 8.1). Through these findings, theoretical and practical conclusions can now be drawn for the improvement of the activities regarding the different aspects of this model.

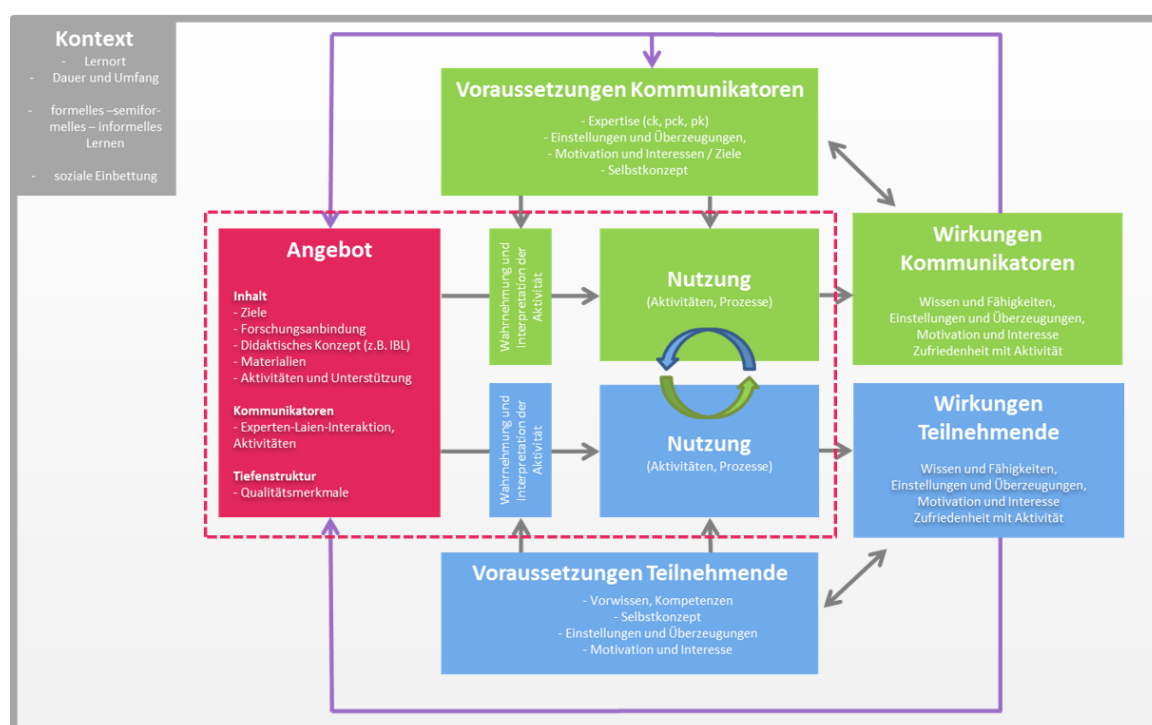


Figure 8.1. Adapted offer/take up-model (Bromme & Goldman, 2014; Helmke, 2012; Storksdieck, Stylinski, & Bailey, 2016); all terms are in German, since this is the model developed and used by the IPN Departement of Chemistry Education

In the following, the conclusions of comprehensive implications for the dissemination of the results and for the redesign of the interventions are presented in the light of the offer/take up-model (colored letters indicate aspects of the model). This describes the fourth step of the design-based research approach.

8.3.1 How Modern Learning Environments Should be Designed (Theoretical Implications)

As already pointed out in Section 4.1, the use of digital media in science lessons can still be expanded (especially in community schools). The results showed that computer simulations are an important tool for teaching particularly complex current topics such as SSI. Therefore, they should be used more often in school and in out-of-school science activities. This should be promoted by improving the digital infrastructure of institutions and by systematically improving the **media competence** of teachers and educators. However, teaching does not necessarily improve with only the

use of digital media (Hattie 2019). **Good integration** into the lessons is therefore very important. In addition, the methods must be of **high quality**. As already mentioned, students today are no longer fascinated by the digital medium itself because they are surrounded by it in their daily lives. This requires a high effort for development on a technical and content level, but it is worth investing in because of the educational benefits described above.

When developing digital methods, special attention must be paid to good **instructional support**. Otherwise, learning benefits may be lost due to a high **cognitive load**. Furthermore, a high level of **interactivity** and the possibility of **self-determined action** within the simulation can be conducive to learning challenging content. In order to promote **communication competence** in the self-determined work with digital media, it is recommended to work in groups or with a partner. In this way, the frequently observed low level of knowledge acquisition in exploratory learning studies using computer simulations can be avoided. The **credibility of the methods** and the promotion of **trust in science** is, as reported, very important to facilitate learning science content and to avoid science denialism. Therefore, this aspect should also be taken into account in science education activities. Therefore paying attention to an **authentic communication** of science is recommended.

8.3.2 How to Develop Modern Learning Environments (Practical Implications)

The development of authentic learning environments on current complex topics with high content quality, which are technically well implemented and didactically adequately designed, should be done in an interdisciplinary approach. With this co-design process it is possible to fulfill all three aspects of didactic reconstruction (see Section 2) in the best possible way. Co-design entails unique benefits for the development of outreach activities but also challenges. Probably the greatest challenge is the negotiation of communication goals (Section 2.3.1). Above all, the finding of a compromise between content complexity and didactic implementation holds great potential for controversy. Thus, the goals should be defined in such a way that the content knowledge is always correct, but is reduced to the skills of the target group. Both in the determination of objectives and in the further implementation, problems of coherence may arise due to fundamentally different functional language in the different disciplines. For the whole process, it is therefore advisable to assign a mediator who has insight into all relevant fields. Of course, this process takes longer than developing an outreach activity with only didactics/educators or only experts would. However, due to the high quality of the learning opportunities, an interdisciplinary approach such as the Kieler Forschungswerkstatt is frequently using in student laboratories. Another major advantage is that this process of interdisciplinary cooperation opens up new research perspectives. With regard to the project presented here, for example, the research focus “trust” was shaped by the considerations of the marine scientists. A particular advantage can be gained if the development process is presented to the students in a transparent way. In schools, methods are often used that pretend to reflect science but, on closer inspection, do not sufficiently fulfill scientific legitimacy. To ensure that the

students understand that these methods are science-based, the development process must be presented in a comprehensible way. It is implied that this will increase credibility in the activities and allow students to change their ideas about science. Competencies in scientific inquiry and scientific literacy might thus be improved. Even though this process is time- and personnel intensive, this doctoral thesis shows that it is worth it!

With regard to the requirements of modern science education for more integration of digital methods discussed at the beginning of this section, digital methods are beneficial and important, but the hands-on experience should not be forgotten. Especially in the context of promoting interest, hands-on experiences are very important and should stay an integral part of science teaching in school and in out-of-school education. Therefore, if for practical reasons the use of two different methods is not feasible, the single use of a (well-developed) simulation is to be preferred when conveying content knowledge is the main focus. If the focus is on promoting interest, experiments might be preferred. Results implicate that the combination of experimental and simulation-based learning tools represents an effective learning environment for complex current topics such as SSI in science education. Students can especially benefit from the sequence of first experiments and second simulation. This approach offers the opportunity to combine cognitive and motivational advantages profitably. Therefore, it is recommended that such a combination should be used more often in diverse science education activities.

8.4 OUTLOOK

To complete the fourth step of the design-based research approach, results can be fed back into the design of the activities through the following aspects.

A practical solution to increase the situational interest when working on the simulation might be to reduce the working time. Based on individual feedback discussions, it is also advocated to increase the working time of the experiments. The resulting time adjustment of the student lab day has already been tested with other classes that did not participate in the evaluation. Students then worked only one hour on the simulation and 15 minutes longer on each experiment. It was perceived that the students' feedback was higher in terms of motivation. However, an empirical study of this adaptation is highly recommended. It is also questionable whether the learning advantage of the simulation can be found even with reduced working time.

Based on the empirical results, working first on the experiments and then on the simulation is recommended from a didactic point of view. In the survey, however, nearly 40% of students still voted for the reverse order. So maybe an activity could be developed where students can choose which sequence they would prefer. In this way, the students could decide individually whether they want to learn individual processes first and then work on the correlations or vice versa.

In order to promote the teachers' media skills and to reduce any fear of complex simulations, further training for teachers is also planned. The aim is to practice the use of the simulation and to convey the underlying knowledge so that teachers can ensure that the activities are appropriately embedded in their lessons.

From a research perspective as well as from a personal point of view, it would be interesting to expand the target group in the future and to include students with lower preconditions. The participants of the interventions had overall good marks, a high level of trust, and probably dedicated teachers. The schools generally came from well-situated areas. It would be interesting to address students who – for various reasons – are often underrepresented in student laboratories like groups from disadvantaged areas. One starting point for this purpose are the efforts of the Kieler Forschungswerkstatt to extend their services to the eastern shore of the Bay of Kiel. One idea would be to adapt the program "Future of the Baltic Sea" to work with scientifically less educated participants. For this purpose, the content should be further structured and more internal differentiation should be enabled.

There are already concrete plans to further develop the student lab day within the framework of the project "Future of MINT Learning" of the Telecom Foundation. This project aims to improve the use of digital media in MINT subjects (mathematics, informatics, natural sciences, and technology). To this end, the actual demand for digital media in MINT subjects has been analyzed. Subsequently, new teaching concepts will be developed that will be incorporated into the training and further education of MINT teachers. The student lab day "Future of the Baltic Sea" represents the basis for such a concept. It is intended to further develop this activity into a completely digital service for schools. Therefore, the website will be adapted to the use at school and some simplifications will be developed, especially in the scripts, so that the simulation can be carried out without specialized staff (as in the student laboratory). Additionally, the experiments will be redesigned so that they can be processed as digital exercises. The focus will then be on the analyses of scientific data on the changes in the Baltic Sea. These adaptations are of even greater relevance in times of the Covid-19 pandemic and the resulting efforts to increase the digitalization of teaching. To provide an insight into authentic science without the infrastructural environment of an out-of-school learning location, it is possible to use videos of scientists. From a research perspective, it would be interesting to compare the digital activity in the school with the student lab day in terms of effects and use of the participants. The investigation of critical thinking aspects of the students is already planned. Another research aspect presents the investigation of emotional appeal and affective design, for example. Science communication research has shown that the emotionality of content and images affects their use. Emotional reactions influence, for example, how attractive a topic appears. Especially with emotionally charged topics such as climate change, it would be interesting to find out whether this also influences the educational effects.

As found out in this doctoral thesis, the students' prior knowledge of the changes in the Baltic Sea was quite limited. Such topics often cannot be adequately conveyed in school due to the lack of expertise of teachers or the lack of equipment in schools. However, the understanding of topics like this is highly important to enable students to actively engage in society and to contribute to sustainable development (Section 2.2). Therefore, outreach activities to communicate current marine biology issues (especially in terms of climate change) should be further promoted. For these reasons and to enable the important hands-on experiences, the school lab day "Baltic Sea of the Future" will be offered further with the already mentioned improvements in the program of the Kieler Forschungswerkstatt, as far as the pandemic situation allows.

Ideally, these two types of activities (digital activities at school and on-site activities in the student laboratory) do not compete with each other but rather complement each other structurally and conceptually. They could be an example of how to better link school and out-of-school activities and how synergies can be created. The formal educational offerings at school could thus primarily develop a content basis and the informal activities in the student laboratory could increase interest through an authentic insight into scientific research and deepens the understanding. By the systematic development of such an Educational Ecosystem both advantages can be used optimally.

CLOSING WORDS

Although this doctoral thesis represents only a small contribution to the understanding of the effects of learning methods, it nevertheless provides evidence and implications that can positively influence the development of modern outreach activities. The interventions were able to communicate the relationship between human actions and the state of ecological systems on the one hand, and the feedback effects of this state on human activities on the other. Thus, another small piece of the puzzle could be set to achieve overall educational goals: The development of appropriate knowledge and competencies to prepare young people adequately for life in today's as well as future society and to enabling them to contribute to sustainable development of our world.

"Understanding the ocean's influence on you and your influence on the ocean" (Definition of ocean literacy, Ocean Literacy Network (2015))

This work will hopefully motivate other educators, marine biologists, teachers, or psychologists to continue to pursue the goal of communicating and exploring the wonderful world of marine science in inspiring and innovative ways.

“Mithilfe von Experimenten und Simulationen kann man Wissen um einiges effektiver übermitteln. Mit solchen Methoden sollte man mehr in der Schule arbeiten, das würde sehr viel bringen!!! Hat mir viel gebracht (: Danke.”⁶

⁶ Student statement in the free comment field evaluating the methods used in the student lab day

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APPENDIX

APPENDIX A

Used Instruments Study I


  

Teil B: Räumliches Vorstellungsvermögen


In diesem Test sollen Sie sich vorstellen, wie ein Stück Papier gefaltet wird. Jede Aufgabe besteht aus Abbildungen, die auf der linken Seite der senkrechten Linie und auf der rechten Seite der Linie stehen. Schauen Sie sich bitte das untere Beispiel an.


Die Abbildungen auf der linken Seite zeigen ein quadratisches Stück Papier, das Schritt für Schritt gefaltet wurde. Nachdem das Papier gefaltet wurde, wurden ein oder mehrere Löcher in das Papier gestanzt. Die Löcher wurden durch alle Lagen des gefalteten Papiers gestanzt. Die fünf Abbildungen auf der rechten Seite der senkrechten Linie zeigen, wie das Papier aussehen könnte, wenn man es wieder auseinanderfaltet. Das heißt, wo sich die Löcher dann befinden könnten. Nur eine dieser 5 Abbildungen ist richtig. Ihre Aufgabe ist es, die richtige Abbildung herauszufinden. Kennzeichnen Sie diese Abbildung, indem Sie diese ankreuzen.


Beispiel:





|

A


B


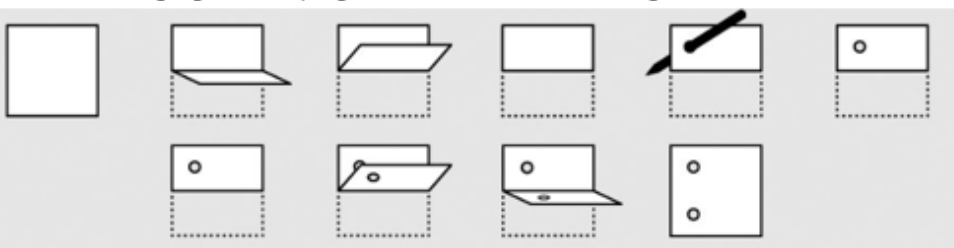
C


D


E


Die richtige Antwort in diesem Beispiel ist C und sollte deshalb angekreuzt werden.

Die untere Darstellung zeigt wie das Papier gefaltet wurde und warum C die richtige Antwort ist.



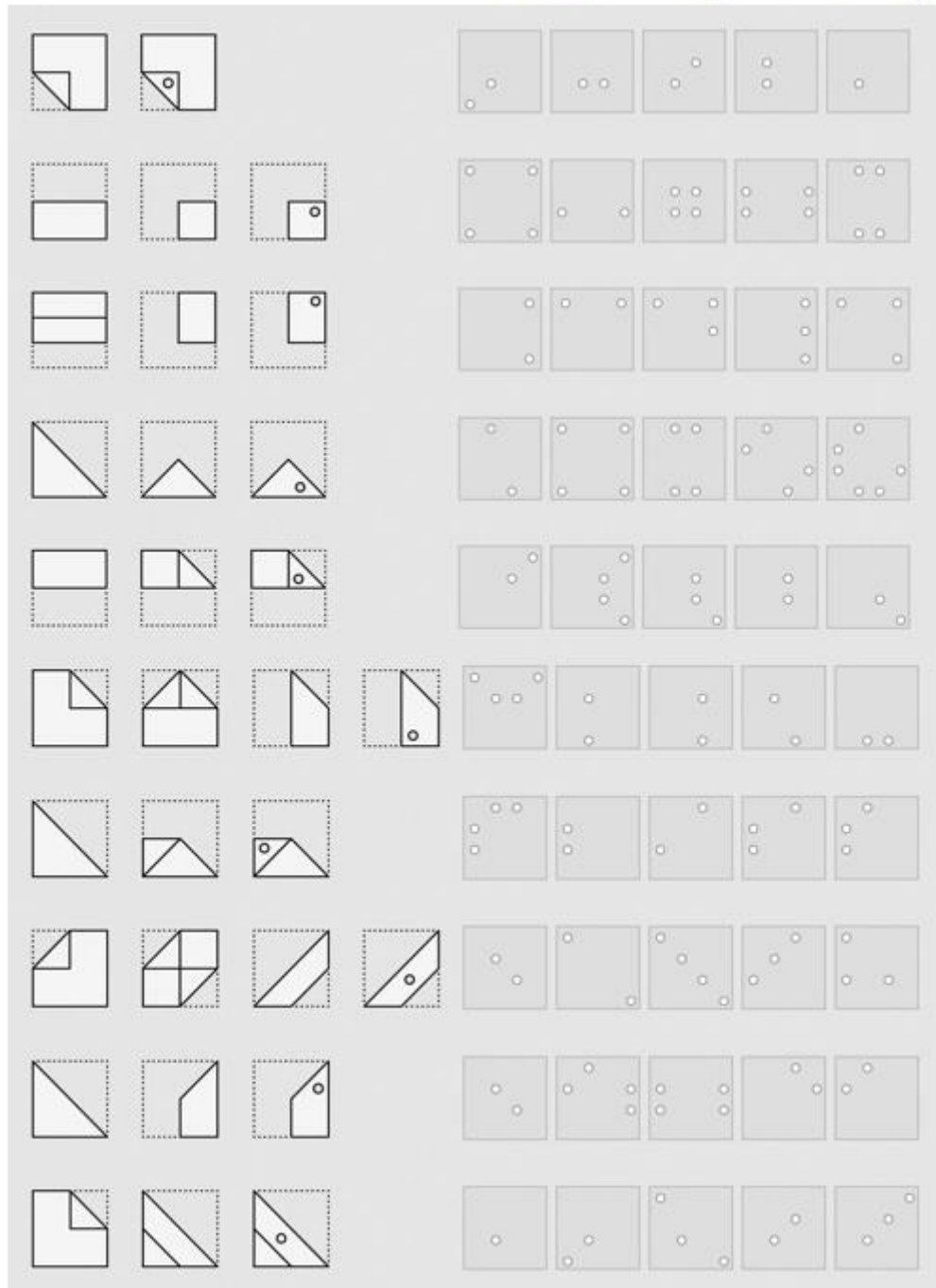
Alle Faltungen, die gemacht wurden, sind in den Abbildungen gezeigt. Das Papier wurde ansonsten nicht bewegt oder verändert.

Bitte erinnern Sie sich daran, die richtige Antwort zeigt die richtige Position der Löcher wenn das Papier vollständig aufgefalted wird.

Ihre Punktzahl in diesem Test errechnet sich aus der Anzahl der richtig angekreuzten Antworten minus der Anzahl der falsch angekreuzten Antworten. Es ist also nicht vorteilhaft zu raten, es sei denn Sie können bestimmte Antworten ausschließen. Arbeiten Sie bitte so schnell Sie können, ohne dabei ungenau zu werden.

Sie haben drei Minuten Zeit für diesen Test. Bitte erst umblättern, wenn Sie dazu aufgefordert werden!

Seite | 2



Sie haben drei Minuten Zeit für diesen Test. Bitte erst umblättern, wenn Sie dazu aufgefordert werden!

Teil C: Lernpräferenz und Fachwissen

Lernmaterial wird manchmal verbal präsentiert (z.B. durch geschriebenen Text oder eine gesprochene Erklärung), manchmal visuell (z.B. durch beschriftete Illustrationen, Graphen oder kommentierte Animationen). Bitte kreuzen Sie an, wie Sie Ihre Lernpräferenz einschätzen würden!

Eindeutig verbal	Gemäßigt verbal	Eher verbal als visuell	Zu gleichen Teilen verbal und visuell	Eher visuell als verbal	Gemäßigt visuell	Eindeutig visuell
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Bitte beantworten Sie folgende Fragen zu Ihrem Fachwissen:

- Ist Ihnen bereits das Problem der Ozeanversauerung bekannt? ☐ ja ☐ nein ☐ teils-teils
- Haben Sie bereits das Thema Ozeanversauerung in der Schule bearbeitet? ☐ ja ☐ nein
- Welche Eigenschaften treffen auf Säuren zu? Mehrere Antworten sind richtig.
 - ☐ Durch die Reaktion von einer Säure mit Wasser entstehen Oxonium-Ionen (H_3O^+).
 - ☐ Säuren können Protonen (H^+) von einem Reaktionspartner aufnehmen.
 - ☐ Säuren reagieren mit Wasser unter der Bildung von Salzen.
 - ☐ Säuren können Protonen (H^+) an einen Reaktionspartner übertragen.
 - ☐ Durch die Reaktion von einer Säure mit Wasser entstehen Hydroxidionen (OH^-).
- Wie hoch ist die aktuelle CO_2 -Konzentration der Atmosphäre? (Angabe in ppm = parts per million)
 - ☐ 275 ppm ☐ 1005 ppm
 - ☐ 885 ppm ☐ 408 ppm
- Immer häufiger beobachten Wissenschaftler, dass Korallen (Organismen aus Kalk: Calciumcarbonat, $CaCO_3$) nicht in der Lage sind, ihr Skelett ausreichend schnell für die Bildung von Korallenriffen aufzubauen. Welche Aussage diesbezüglich stimmt?
 - ☐ Kalk ist eine chemische Verbindung aus Calcium, Kohlenstoff und Sauerstoff. Durch den erhöhten Eintrag von CO_2 wird so viel Sauerstoff verbraucht, dass die Korallen daher ihr Kalkskelett nicht mehr aufbauen können.
 - ☐ Der niedrigere pH-Wert im Meer sorgt für eine geringere physiologische Aktivität von Korallen, weshalb sie nicht ausreichend schnell ihr Skelett aufbauen können.
 - ☐ Die durch eine erhöhte CO_2 -Konzentration aufgewärmte Atmosphäre (Treibhauseffekt) sorgt für eine höhere Durchschnittstemperatur der Meere. Korallen sind jedoch Kaltwasserorganismen und können daher ihr Kalkskelett nicht mehr ausreichend schnell aufbauen.
 - ☐ Durch die Pufferwirkung von Meerwasser kommt es zu einem Rückgang der Carbonat-Ionen (CO_3^{2-}), welche jedoch für die Bildung von Kalk benötigt werden.

Teil D: Interesse und Selbstkonzept

Bitte beantworten Sie folgende Fragen zu Ihrem Interesse und Selbstkonzept im Bereich der **Chemie** und der **Biologie** als Wissenschaft. Seien Sie dabei bitte ganz ehrlich. Bitte kreuzen Sie in jeder Zeile nur ein Kästchen an.

Wie sehr stimmen Sie mit den folgenden Aussagen überein?		stimmt gar nicht	stimmt wenig	stimmt ziemlich	stimmt völlig
1	Im Allgemeinen macht es mir Spaß, mich mit chemischen Themen zu befassen.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2	Obwohl ich mir Mühe gebe, fällt mir die Chemie schwer.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
3	Komplexe Wissenszusammenhänge in der Chemie kann ich schnell und richtig erfassen.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
4	Wenn ich in der Chemie etwas nicht verstanden habe, denke ich, dass ich es wohl nie verstehen werde.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
5	Für die Chemie bin ich einfach begabt.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
6	In der Chemie kann ich mir leicht Wissen aneignen.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
7	Ich lese gerne etwas über Chemie .	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
8	Ich eigne mir gerne neues Wissen in der Chemie an.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
9	Ich beschäftige mich gerne mit chemischen Fragestellungen.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
10	Ich bin interessiert, Neues in der Chemie zu lernen.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

11	Obwohl ich mir Mühe gebe, fällt mir die Biologie schwer.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
12	Ich eigne mir gerne neues Wissen in der Biologie an.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
13	Im Allgemeinen macht es mir Spaß, mich mit biologischen Themen zu befassen.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
14	Ich lese gerne etwas über Biologie .	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
15	Komplexe Wissenszusammenhänge in der Biologie kann ich schnell und richtig erfassen.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
16	Wenn ich in der Biologie etwas nicht verstanden habe, denke ich, dass ich es wohl nie verstehen werde.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
17	Für die Biologie bin ich einfach begabt.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
18	Ich bin interessiert, Neues in der Biologie zu lernen.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
19	In der Biologie kann ich mir leicht Wissen aneignen.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
20	Ich beschäftige mich gerne mit biologischen Fragestellungen.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Wie sehr stimmen Sie mit den folgenden Aussagen überein?	uninteressant	wenig interessant	interessant	sehr interessant
1 Ich finde die Meeresforschung...	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2 Ich finde das Fach Chemie...	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
3 Ich finde das Teilgebiet "Ozeanversauerung"...	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Teil E: Vertrauen in Wissenschaftlerinnen und Wissenschaftler

Im nächsten Abschnitt möchten wir erfahren inwieweit Sie der Wissenschaft an sich und den Wissenschaftlerinnen und Wissenschaftlern vertrauen.

Bitte kreuzen Sie in jeder Zeile nur ein Kästchen an.

Wie sehr stimmen Sie mit den folgenden Aussagen überein?	stimmt gar nicht	stimmt wenig	stimmt teils-teils	stimmt ziemlich	stimmt völlig
1 Wir können Naturwissenschaftlerinnen und Naturwissenschaftlern vertrauen, ihre Entdeckungen zu veröffentlichen, auch wenn ihnen die Ergebnisse selbst nicht gefallen.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2 Ich bin davon überzeugt, dass die Arbeit von Naturwissenschaftlerinnen und Naturwissenschaftlern das Leben der Menschen verbessert.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
3 Wir sollten uns auf die Arbeit von Naturwissenschaftlerinnen und Naturwissenschaftler verlassen.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
4 Wir sollten darauf vertrauen, dass Naturwissenschaftlerinnen und Naturwissenschaftler seriös arbeiten.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
5 Wir sollten darauf vertrauen, dass Naturwissenschaftlerinnen und Naturwissenschaftler in ihrer Arbeit ethisch verantwortlich arbeiten.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
6 Wissenschaftliche Theorien sind glaubwürdig.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Teil F: Überzeugungen

Im Folgenden werden Sie zu ihren Überzeugungen zur Naturwissenschaft befragt. Bitte geben Sie an, in welchem Ausmaß Sie den Aussagen zustimmen. Bitte kreuzen Sie in jeder Zeile nur ein Kästchen an.

Wie sehr stimmen Sie mit den folgenden Aussagen überein?		stimmt gar nicht	stimmt kaum	stimmt teils- teils	stimmt ziemlich	stimmt völlig
1	Manchmal verändern sich die Vorstellungen in den Naturwissenschaften.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2	Was Naturwissenschaftler herausfinden, muss man glauben.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
3	Gute Theorien stützen sich auf die Ergebnisse aus vielen verschiedenen Experimenten.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
4	Naturwissenschaftler stimmen immer darin überein, was in ihrem Fach wahr ist.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
5	Die Ideen zu naturwissenschaftlichen Experimenten kommen daher, dass man neugierig ist und darüber nachdenkt, wie etwas funktioniert.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
6	Einige Vorstellungen in den Naturwissenschaften sind heute anders als das, was Naturwissenschaftler früher dachten.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
7	Was man in einem Naturwissenschaftsbuch liest, ist sicher wahr.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
8	Ein wichtiger Teil der Naturwissenschaften ist es, Experimente durchzuführen, um neue Ideen zu finden.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
9	In den Naturwissenschaften ist beinahe alles bekannt; es gibt nicht mehr viel, was man herausfinden könnte.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
10	Was in Naturwissenschaftsbüchern steht, muss man glauben.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
11	In den Naturwissenschaften können sich neue Vorstellungen aus den eigenen Fragen und Experimenten entwickeln.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
12	Die Vorstellungen in Naturwissenschaftsbüchern verändern sich manchmal.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
13	Alle Fragen in den Naturwissenschaften haben genau eine Lösung.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
14	Es ist wichtig, eine konkrete Vorstellung zu haben, bevor man mit einem Experiment beginnt.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Wie sehr stimmen Sie mit den folgenden Aussagen überein?		stimmt gar nicht	stimmt kaum	stimmt teils- teils	stimmt ziemlich	stimmt völlig
15	Der wichtigste Teil der Naturwissenschaften ist die Suche nach den einzig richtigen Lösungen.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
16	Nur Naturwissenschaftler wissen genau, was in ihrem Fach wahr ist.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
17	In den Naturwissenschaften kann es mehrere Wege geben, um Vorstellungen zu überprüfen.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
18	Durch neue Entdeckungen kann sich verändern, was Naturwissenschaftler für wahr halten.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
19	Was der Lehrer im Naturwissenschaftsunterricht sagt, ist wahr.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
20	Es gibt manche Fragen in den Naturwissenschaften, die auch Naturwissenschaftler nicht beantworten können.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
21	Ein Experiment ist ein guter Weg um herauszufinden, ob etwas wahr ist.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
22	Es gibt nur die eine Lösung, wenn Naturwissenschaftler einmal das Ergebnis eines Experiments gefunden haben.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
23	Manchmal ändern Naturwissenschaftler ihre Meinung darüber, was in ihrem Fach wahr ist.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
24	Es ist wichtig, Experimente mehr als einmal durchzuführen, um Ergebnisse abzusichern.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
25	Das Wissen in den Naturwissenschaften ist für alle Zeit wahr.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
26	Gute Ideen in den Naturwissenschaften können von jedem kommen, nicht nur von Naturwissenschaftlern.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Vielen Dank für Ihre Unterstützung!

Post-Fragebogen (Simulation)

Liebe Schülerin, lieber Schüler,

bitte beantworten Sie nur noch diese Fragen.

Wir bedanken uns herzlich für Ihre Unterstützung!

Weiterhin sind alle Angaben selbstverständlich anonym! Bitte tragen Sie auch hier bitte Ihren persönlichen Code zur Zuordnung der Prä- und Postfragebögen ein:

Kreuzen Sie bitte den 1. Buchstaben Ihres Vornamens an:																									
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z

Kreuzen Sie bitte den 1. Buchstaben des Vornamens Ihrer Mutter an:																									
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z

Kreuzen Sie bitte Ihren GeburtsTAG an:																														
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31

Teil A: Kognitive Belastung

Zunächst zwei Fragen zu den Anforderungen der Simulation. Bitte versuchen Sie, sich so genau wie möglich einzuschätzen:

Wie leicht oder schwer war die Simulation zu verstehen?						
Sehr leicht	Leicht	Eher leicht	Weder leicht noch schwer	Eher schwer	Schwer	Sehr schwer
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Bei der Bearbeitung der Simulation war meine mentale Anstrengung...						
Sehr gering	Gering	Eher gering	Weder gering noch hoch	Eher hoch	Hoch	Sehr hoch
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Teil B: Handhabbarkeit & Nützlichkeit der Simulation

Es folgen Fragen zur Handhabbarkeit und Nützlichkeit der Simulation. Bitte machen Sie in jeder Zeile nur ein Kreuz.

	Wie sehr stimmen Sie mit den folgenden Aussagen überein?	stimmt gar nicht	stimmt wenig	stimmt ziemlich	stimmt völlig
1	Die Handhabung der Simulation war mir klar.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2	Was ich bei der Station zur Ozeanversauerung gelernt habe, kann ich später bestimmt gut gebrauchen.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
3	Es hat mir keine Probleme bereitet, mit der Simulation zu arbeiten.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
4	Durch die Bearbeitung der Simulation zum Thema Ozeanversauerung sind mir meine eigenen Wissenslücken bewusst geworden.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
5	Ich kann mir vorstellen, dass die Bearbeitung von Simulationen beim Lernen eines bestimmten Wissensgebietes hilfreich ist.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
6	Bei der Bearbeitung der Simulation fand ich es schwierig den Zusammenhang der einzelnen Abschnitte zu verstehen.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
7	Es war mein persönliches Ziel, die Station zur Ozeanversauerung so gut wie möglich zu erlernen.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
8	Für das Bearbeiten der Simulation hätte ich gerne mehr Zeit zur Verfügung gehabt.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
9	Mit der Station zur Ozeanversauerung kann ich meine Wissenslücken zu diesem Thema schließen	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
10	Die Simulation war leicht zu bearbeiten.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
11	Bei der Bearbeitung der Simulation fand ich es schwierig den Inhalt zu verstehen.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
12	Bei der Bearbeitung der Simulation habe ich die Gelegenheit gehabt, mein chemisches Wissen zu zeigen.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
13	Die Bearbeitung der Simulation hat mir geholfen, das Thema Ozeanversauerung besser zu verstehen.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
14	Mit der Station zur Ozeanversauerung konnte ich mir eine Menge nützliches Wissen aneignen	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
15	Die Bearbeitung der Simulation ist mir insgesamt schwer gefallen.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Teil C: Fachwissen

In diesem Abschnitt bitten wir Sie Fragen zum Thema Ozeanversauerung auszufüllen.

1. Welches der folgenden Merkmale kennzeichnet eine Säure-Base-Reaktion?
 - ☐ Die Reaktion verläuft heftig.
 - ☐ Protonen werden übertragen.
 - ☐ Es bildet sich ein Niederschlag.
 - ☐ Eine Farbänderung tritt auf.
2. Welche Eigenschaften treffen auf Säuren zu? Mehrere Antworten sind richtig.
 - ☐ Durch die Reaktion von einer Säure mit Wasser entstehen Oxonium-Ionen (H_3O^+).
 - ☐ Säuren können Protonen (H^+) von einem Reaktionspartner aufnehmen.
 - ☐ Säuren reagieren mit Wasser unter der Bildung von Salzen.
 - ☐ Säuren können Protonen (H^+) an einen Reaktionspartner übertragen.
 - ☐ Durch die Reaktion von einer Säure mit Wasser entstehen Hydroxidionen (OH^-).
3. Wenn man zwei Stoffe zusammen gibt, reagieren diese manchmal miteinander. Nach einer Zeit ist aber keine weitere Reaktion mehr zu erkennen. Wie kann man dies interpretieren?
 - ☐ Die beiden Ausgangsstoffe sind nicht mehr vorhanden, deshalb endet die Reaktion.
 - ☐ Die Reaktion läuft noch weiter, aber nicht mehr so stark. Daher kann man nicht mehr erkennen.
 - ☐ Die Reaktion verläuft in beide Richtungen. Nach einer Zeit werden immer gleich viele Produkte gebildet und wieder abgebaut, deswegen kann man keine Veränderung mehr beobachten.
 - ☐ Die Aktivierungsenergie, die zum Starten der Reaktion notwendig ist, ist aufgebraucht.
4. Was passiert wenn CO_2 im Meerwasser gelöst wird?
 - ☐ Es entstehen hauptsächlich Hydrogencarbonat-Ionen (HCO_3^-).
 - ☐ Es entsteht hauptsächlich Kohlensäure (H_2CO_3).
 - ☐ Der pH-Wert steigt.
 - ☐ Der Gehalt an Calciumcarbonat-Ionen steigt.
5. Wie hoch ist die aktuelle CO_2 -Konzentration der Atmosphäre? (Angabe in ppm = parts per million)
 - ☐ 275 ppm
 - ☐ 1005 ppm
 - ☐ 885 ppm
 - ☐ 408 ppm

6. Durch die Verbrennung fossiler Energieträger steigt der CO_2 -Gehalt der Atmosphäre. Welche Auswirkungen hat dieser Anstieg des CO_2 -Gehalts in unserer Atmosphäre auf die Konzentration folgender Stoffe im Meerwasser?

Geben Sie an, ob die Verbindungen zukünftig in einer **höheren Konzentration** (\uparrow) oder in einer **niedrigeren Konzentration** (\downarrow) vorliegen.

Stoff	Konzentration (\uparrow oder \downarrow)
CO_2 (Kohlenstoffdioxid)	
HCO_3^- (Hydrogencarbonat)	
CO_3^{2-} (Calciumcarbonat)	

7. Immer häufiger beobachten Wissenschaftler, dass Korallen (Organismen aus Kalk: Calciumcarbonat, CaCO_3) nicht in der Lage sind, ihr Skelett ausreichend schnell für die Bildung von Korallenriffen aufzubauen. Welche Aussage diesbezüglich stimmt?

- ☐ Kalk ist eine chemische Verbindung aus Calcium, Kohlenstoff und Sauerstoff. Durch den erhöhten Eintrag von CO_2 wird so viel Sauerstoff verbraucht, dass die Korallen daher ihr Kalkskelett nicht mehr aufbauen können.
- ☐ Der niedrigere pH-Wert im Meer sorgt für eine geringere physiologische Aktivität von Korallen, weshalb sie nicht ausreichend schnell ihr Skelett aufbauen können.
- ☐ Die durch eine erhöhte CO_2 -Konzentration aufgewärmte Atmosphäre (Treibhauseffekt) sorgt für eine höhere Durchschnittstemperatur der Meere. Korallen sind jedoch Kaltwasserorganismen und können daher ihr Kalkskelett nicht mehr ausreichend schnell aufbauen.
- ☐ Durch die Pufferwirkung von Meerwasser kommt es zu einem Rückgang der Carbonat-Ionen (CO_3^{2-}), welche jedoch für die Bildung von Kalk benötigt werden.

8. Welchen Einfluss haben Druck und Temperatur auf die Löslichkeit von CO_2 im Wasser? Mehrere Antworten sind richtig.

- ☐ Je höher der Druck, desto mehr CO_2 löst sich im Wasser.
- ☐ Druck und Temperatur haben keinen Einfluss auf die Löslichkeit von CO_2 .
- ☐ Je niedriger die Temperatur, desto weniger CO_2 löst sich im Wasser.
- ☐ Je höher der Druck, desto weniger CO_2 löst sich im Wasser.
- ☐ Je niedriger die Temperatur, desto mehr CO_2 löst sich im Wasser.

9. Seit Beginn der Industrialisierung ist der pH-Wert des Oberflächenwassers der Meere im Mittel um 0,1 Einheiten gesunken. Welche Aussagen über den pH-Wert stimmen? Mehrere Antworten sind richtig.

- ☐ Der pH-Wert gibt Auskunft über den sauren oder basischen Charakter einer wässrigen Lösung.
- ☐ Eine Verdopplung des pH-Werts, z.B. von pH-Wert = 2 auf pH-Wert = 4, bedeutet, dass der basische bzw. saure Charakter der Lösung sich verdoppelt hat.
- ☐ Beim pH-Wert handelt es sich um eine logarithmische Skala.
- ☐ Die pH-Wert Skala ist eingeteilt in: <7 = basisch, 7 = neutral, >7 = sauer.
- ☐ Je mehr Oxonium-Ionen (H_3O^+) in der Lösung vorkommen, desto höher ist der pH-Wert

Teil D: Interesse

Bitte beantworten Sie folgende Fragen zu der Simulation. Seien sie dabei bitte ganz ehrlich. Bitte kreuzen Sie in jeder Zeile nur ein Kästchen an.

Wie sehr stimmen Sie mit den folgenden Aussagen überein?	uninteressant	wenig interessant	interessant	sehr interessant
1a Ich finde das Fach Chemie....	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
1b Ich finde die Meeresforschung...	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
1c Ich finde das Teilgebiet Ozeanversauerung...	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Wie sehr stimmen Sie mit den folgenden Aussagen überein?	stimmt gar nicht	stimmt wenig	stimmt ziemlich	stimmt völlig
2a Beim Bearbeiten der Simulation habe ich mich wohl gefühlt.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2b Ich werde mit Freunden oder der Familie über Dinge sprechen, die ich bei dieser Station gelernt habe.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2c So eine Simulation, wie wir sie bei dieser Station bearbeitet haben, würde ich auch in meiner Freizeit bearbeiten.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2d Beim Bearbeiten der Simulation ist die Zeit sehr langsam vergangen.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2e Ich würde gerne mehr über die Simulation lernen, die wir in dieser Station bearbeitet haben.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2f Dass wir heute die Simulation gemacht haben, ist mir persönlich wichtig.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2g Ich werde außerhalb des Unterrichts über Dinge nachdenken, die wir in dieser Station gesehen oder angesprochen haben.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2g Die Bearbeitung der Simulation war langweilig.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2i Der heutige Besuch ist für mich persönlich von Bedeutung.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2j Ich werde in Büchern oder im Internet nachlesen, um mehr Informationen über das Thema Ozeanversauerung zu bekommen.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2k Dass wir heute die Simulation gemacht haben, erscheint mir sinnvoll.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2l Die Bearbeitung der Simulation hat mir keinen Spaß gemacht.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Teil E: Vertrauen in die Wissenschaft und Wissenschaftler/innen

Im nächsten Abschnitt möchten wir erfahren inwieweit Sie der Wissenschaft an sich und den Wissenschaftlerinnen und Wissenschaftlern vertrauen.

Bitte kreuzen Sie in jeder Zeile nur ein Kästchen an.

Wie sehr stimmen Sie mit den folgenden Aussagen überein?	stimmt gar nicht	stimmt wenig	stimmt teils-teils	stimmt ziemlich	stimmt völlig
1 Wir können Naturwissenschaftlerinnen und Naturwissenschaftlern vertrauen, ihre Entdeckungen zu veröffentlichen, auch wenn ihnen die Ergebnisse selbst nicht gefallen.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2 Ich bin davon überzeugt, dass die Arbeit von Naturwissenschaftlerinnen und Naturwissenschaftlern das Leben der Menschen verbessert.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
3 Wir sollten uns auf die Arbeit von Naturwissenschaftlerinnen und Naturwissenschaftlern verlassen.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
4 Wir sollten darauf vertrauen, dass Naturwissenschaftlerinnen und Naturwissenschaftler seriös arbeiten.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
5 Wir sollten darauf vertrauen, dass Naturwissenschaftlerinnen und Naturwissenschaftler in ihrer Arbeit ethisch verantwortlich arbeiten.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
6 Wissenschaftliche Theorien sind glaubwürdig.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Teil F: Überzeugungen

Im Folgenden werden Sie zu ihren Überzeugungen zur Naturwissenschaft befragt. Bitte geben Sie an, in welchem Ausmaß Sie den Aussagen zustimmen. Bitte kreuzen Sie in jeder Zeile nur ein Kästchen an.

Wie sehr stimmen Sie mit den folgenden Aussagen überein?		stimmt gar nicht	stimmt kaum	stimmt teils- teils	stimmt ziemlich	stimmt völlig
1	Manchmal verändern sich die Vorstellungen in den Naturwissenschaften.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2	Was Naturwissenschaftler herausfinden, muss man glauben.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
3	Gute Theorien stützen sich auf die Ergebnisse aus vielen verschiedenen Experimenten.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
4	Naturwissenschaftler stimmen immer darin überein, was in ihrem Fach wahr ist.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
5	Die Ideen zu naturwissenschaftlichen Experimenten kommen daher, dass man neugierig ist und darüber nachdenkt, wie etwas funktioniert.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
6	Einige Vorstellungen in den Naturwissenschaften sind heute anders als das, was Naturwissenschaftler früher dachten.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
7	Was man in einem Naturwissenschaftsbuch liest, ist sicher wahr.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
8	Ein wichtiger Teil der Naturwissenschaften ist es, Experimente durchzuführen, um neue Ideen zu finden.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
9	In den Naturwissenschaften ist beinahe alles bekannt; es gibt nicht mehr viel, was man herausfinden könnte.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
10	Was in Naturwissenschaftsbüchern steht, muss man glauben.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
11	In den Naturwissenschaften können sich neue Vorstellungen aus den eigenen Fragen und Experimenten entwickeln.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
12	Die Vorstellungen in Naturwissenschaftsbüchern verändern sich manchmal.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
13	Alle Fragen in den Naturwissenschaften haben genau eine Lösung.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
14	Es ist wichtig, eine konkrete Vorstellung zu haben, bevor man mit einem Experiment beginnt.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Wie sehr stimmen Sie mit den folgenden Aussagen überein?		stimmt gar nicht	stimmt kaum	stimmt teils- teils	stimmt ziemlich	stimmt völlig
15	Der wichtigste Teil der Naturwissenschaften ist die Suche nach den einzig richtigen Lösungen.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
16	Nur Naturwissenschaftler wissen genau, was in ihrem Fach wahr ist.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
17	In den Naturwissenschaften kann es mehrere Wege geben, um Vorstellungen zu überprüfen.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
18	Durch neue Entdeckungen kann sich verändern, was Naturwissenschaftler für wahr halten.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
19	Was der Lehrer im Naturwissenschaftsunterricht sagt, ist wahr.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
20	Es gibt manche Fragen in den Naturwissenschaften, die auch Naturwissenschaftler nicht beantworten können.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
22	Ein Experiment ist ein guter Weg um herauszufinden, ob etwas wahr ist.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
23	Es gibt nur die eine Lösung, wenn Naturwissenschaftler einmal das Ergebnis eines Experiments gefunden haben.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
24	Manchmal ändern Naturwissenschaftler ihre Meinung darüber, was in ihrem Fach wahr ist.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
25	Es ist wichtig, Experimente mehr als einmal durchzuführen, um Ergebnisse abzusichern.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
26	Das Wissen in den Naturwissenschaften ist für alle Zeit wahr.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
27	Gute Ideen in den Naturwissenschaften können von jedem kommen, nicht nur von Naturwissenschaftlern.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Vielen Dank für Ihre Unterstützung!

Used Instruments Study II

Pre-Test



<https://ostsee-der-zukunft.experience-science.de/feedback/fragebogen/startbefragung.html>

Intermediate-Test



<https://ostsee-der-zukunft.experience-science.de/feedback/fragebogen/zwischenbefragung-experimente.html>

Post-Test





<https://ostsee-der-zukunft.experience-science.de/feedback/fragebogen/Abschlussbefragung.html>

APPENDIX B

Working Materials Study I

Experiments



OZEAN-VERSÄUERUNG
Saure und alkalische Lösungen

Saure und alkalische Lösungen

Wässrige Lösungen können **sauer**, **neutral** und **basisch** sein. Farbstoffe, die in sauren, neutralen und basischen Lösungen unterschiedliche Farben haben, werden als „**Indikatoren**“ bezeichnet. Ein häufig verwendeter Indikator ist der Universalindikator.

Um exakt zu kennzeichnen, wie sauer oder alkalisch eine Lösung ist, wird häufig der **pH-Wert** angegeben. Die pH-Wert-Skala reicht von 0 bis 14: Neutrale Lösungen haben einen pH-Wert von 7. Bei sauren Lösungen ist der pH-Wert kleiner als 7 und bei alkalischen Lösungen ist der pH-Wert größer als 7. Das heißt: je kleiner der pH-Wert, desto saurer ist die Lösung!

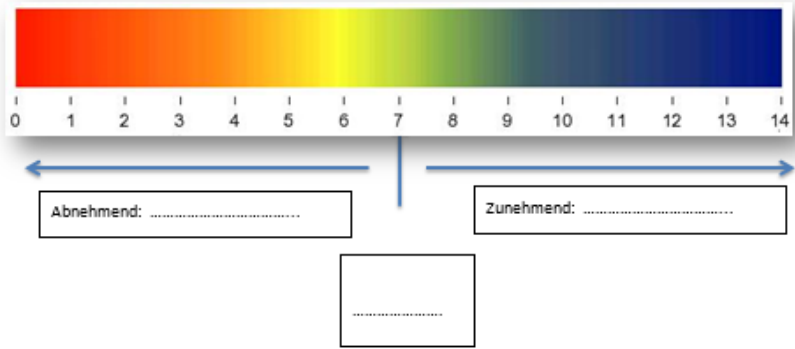


Abb. 1: Die pH-Wert-Skala eines Universalindikators

Aufgaben

- 1) Ergänzen Sie in den Kästchen unter der pH-Skala folgende Begriffe: alkalisch, sauer, neutral!
- 2) Stellen Sie Vermutungen an: Welchen pH-Wert haben folgende Lösungen?

Orangensaft: _____




Seifenlauge: _____

Leitungswasser: _____

Sprudelwasser: _____

Meerwasser: _____

Quelle:
Eisner W, Gietz P, Justus A, Laitenberger K, Nickolay H, Schierle W, Schmidt B, Sternberg M (2007): *elemente chemie 1*. Stuttgart: Klett Verlag.



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Ozeanversauerung

„Seit Beginn der Industrialisierung haben die Weltmeere knapp die Hälfte des Kohlendioxids (CO_2) aus der Verbrennung fossiler Energieträger aufgenommen. Während sich das CO_2 in der Atmosphäre weitestgehend chemisch neutral verhält, also nicht mit anderen Gasen reagiert, ist es im Ozean chemisch aktiv. Gelöstes CO_2 trägt zu einer Absenkung des pH-Wertes bei. Das Meer wird saurer! Dieser Effekt ist bereits messbar: Der pH-Wert des Oberflächenwassers der Meere ist von 8,2 im Mittel um 0,1 Einheiten gesunken.“

Kieler Wissenschaftler erforschen im Rahmen des Exzellenzcluster "Ozean der Zukunft" u.a., welche Faktoren die CO_2 -Aufnahme des Meereswassers beeinflussen und welche Folgen die Ozeanversauerung für das marine Ökosystem hat.

Die verschiedenen Experimentier-Stationen bieten Ihnen die Möglichkeit, sich mit vielen relevanten Fragen rund um die Ozeanversauerung vertiefend zu beschäftigen!



Abb. 1: Mit Hilfe von Mesokosmen untersuchen Wissenschaftler die Folgen der Ozeanversauerung für das marine Ökosystem.

Versuch: Folgen eines erhöhten CO_2 -Gehalts in der Luft für Meereswasser

Durch die Verbrennung von fossilen Energieträgern wie Kohle, Erdgas und Erdöl bringen wir Menschen große Mengen CO_2 (Kohlenstoffdioxid) in die Atmosphäre ein. In der Atmosphäre reflektiert es die von der Erde abgestrahlte Wärme und verursacht so den Treibhauseffekt - das Klima heizt sich auf.

Unsere Ozeane bremsen diese Entwicklung, denn sie können große Mengen CO_2 aufnehmen und speichern. Da etwa zwei Drittel der Erdoberfläche mit Wasser bedeckt sind, können bis zu 40 % der vom Menschen produzierten Kohlenstoffdioxid-Menge von den Ozeanen aufgenommen werden.

Welche Folgen hat das für die Ozeane und die Organismen, die dort leben?

Material

- 1 großes Aquarium
- 2 pH-Elektroden
- 5 Teelichter
- Stoppuhr
- 2 Kristallisierschalen
- 1 Aquariumpumpe mit Sprudelsteinen und Schläuchen
- destilliertes Wasser und Ostseewasser

Versuchsdurchführung

1. Füllen Sie eine Kristallisierschale zu $\frac{1}{2}$ mit Ostseewasser, die andere Kristallisierschale zu $\frac{1}{2}$ mit destilliertem Wasser. Platzieren Sie in beide Kristallisierschalen den Luftsprudler der Aquariumpumpe.
2. Platzieren Sie in beide Kristallisierschalen eine pH-Elektrode. Lesen Sie den Ausgangswert ab und tragen Sie ihn in die Tabelle ein.
3. Entzünden Sie die Teelichter und stellen Sie diese um die Kristallisierschalen. Der Aufbau wird mit dem großen Aquarium abgedeckt. **Achtung!:** Achten Sie darauf, dass sich die Pumpe ebenfalls unter der Abdeckung befindet und die Schläuche nicht über den Teelichtern sind.
4. Schalten Sie die Aquariumpumpe ein (Stecker in Steckdose). Lassen Sie den Versuch 5 Minuten lang laufen. Lesen Sie einmal in der Minute den pH-Wert ab und tragen Sie ihn in die Tabelle ein.

Beobachtung

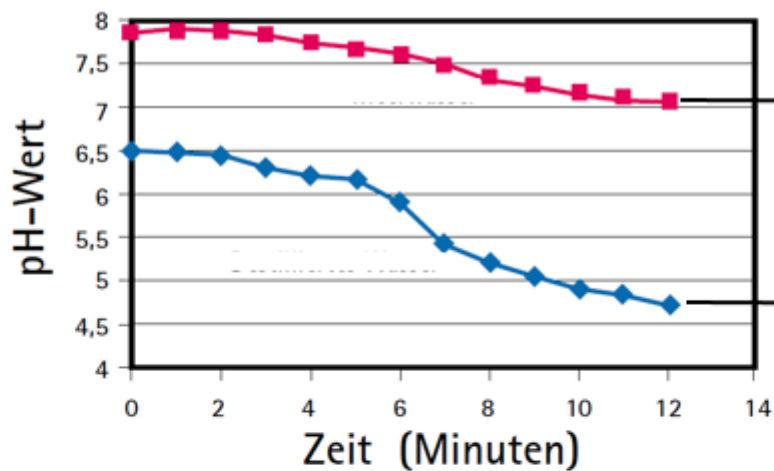
	Zeit in min					
	0	1	2	3	4	5
pH-Wert dest. Wasser						
pH-Wert Ostseewasser						

Aufgaben

- 3) Beschreiben Sie was Sie bei diesem Versuch beobachten konnten. Ist das Wasser basischer oder sauer geworden?

- 4) Meerwasser oder destilliertes Wasser?

Hier sind die Veränderungen des pH-Werts in den Bechergläsern im Laufe der Zeit dargestellt. Ordnen Sie den beiden Graphen die richtige Beschriftung zu.

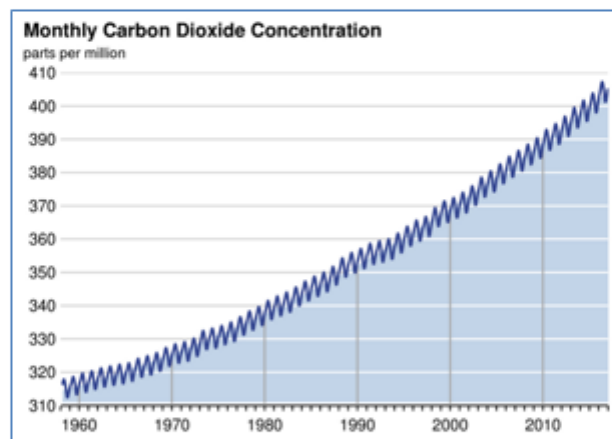


Quelle Versuchsbeschreibung:

Soria-Dengg, Sally (2012): Das andere CO₂-Problem: Ozeanversauerung. BIOACID / Helmholtz-Zentrum für Ozeanforschung (GEOMAR), Kiel.

- 5) Erklären Sie Ihre Beobachtung. Berücksichtigen Sie hierbei die zuvor aufgestellten Reaktionsgleichungen für das Gleichgewichtssystem.

- 6) Bei dem folgenden Diagramm handelt es sich um eine Auswertung des SCRIPPS (Institut of Oceanography, UC. San Diego). Schätzen Sie ab, wie sich die Entwicklung der CO₂-Konzentration der letzten 50 Jahre in der Atmosphäre auf den Zustand der Weltmeere auswirken wird.

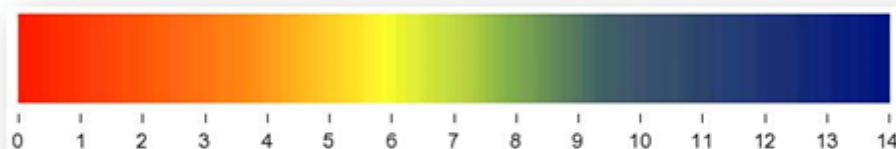


Quelle Abb. 2: <http://scrippsco2.ucsd.edu/#> (Stand 24.04.2018)

Saure und alkalische Lösungen

Wässrige Lösungen können **sauer**, **neutral** und **basisch** sein. Farbstoffe, die in sauren, neutralen und basischen Lösungen unterschiedliche Farben haben, werden als „Indikatoren“ bezeichnet. Ein häufig verwendeter Indikator ist der Universalindikator.

Um exakt zu kennzeichnen, wie sauer oder alkalisch eine Lösung ist, wird häufig der pH-Wert angegeben. Die logarithmische pH-Wert-Skala reicht von 0 bis 14: Neutrale Lösungen haben einen pH-Wert von 7. Bei sauren Lösungen ist der pH-Wert kleiner als 7 und bei alkalischen Lösungen ist der pH-Wert größer als 7. Das heißt: je kleiner der pH-Wert, desto saurer ist die Lösung!



Aufgabe:

1. Ordnen Sie die abgebildeten Flüssigkeiten in der computerbasierten Lernumgebung ihre richtige Position auf der pH-Skala zu.
2. Nennen Sie hier beispielhaft für die genannten Flüssigkeiten den richtigen pH-Wert.
3. Beschreiben Sie den sauren oder basischen Charakter der Flüssigkeit (sauer, eher sauer, neutral, eher basisch, basisch).

Flüssigkeit		pH-Wert	Beschreibung
Ein Glas Leitungswasser			
Eine Batterie			
Orangensaft			
Bleichmittel			
Meerwasser			

Ozeanversauerung

„Seit Beginn der Industrialisierung haben die Weltmeere knapp die Hälfte des Kohlendioxids (CO_2) aus der Verbrennung fossiler Energieträger aufgenommen. Während sich das CO_2 in der Atmosphäre weitestgehend chemisch neutral verhält, also nicht mit anderen Gasen reagiert, ist es im Ozean chemisch aktiv. Gelöstes CO_2 trägt zu einer Absenkung des pH-Wertes bei. Das Meer wird saurer! Dieser Effekt ist bereits messbar: Der pH-Wert des Oberflächenwassers der Meere ist von 8,2 im Mittel um 0,1 Einheiten gesunken.“

Kieler Wissenschaftler erforschen im Rahmen des Exzellenzcluster "Ozean der Zukunft" u.a., welche Faktoren die CO_2 -Aufnahme des Meereswassers beeinflussen und welche Folgen die Ozeanversauerung für das marine Ökosystem hat.

Diese Simulation bietet Ihnen die Möglichkeit, sich mit vielen relevanten Fragen rund um die Ozeanversauerung vertiefend zu beschäftigen!



Abb. 1: Mit Hilfe von Mesokosmen untersuchen Wissenschaftler die Folgen der Ozeanversauerung für das marine Ökosystem.

4. Erklären Sie warum die Kalkbildung bei erhöhtem CO_2 -Gehalt der Atmosphäre erschwert ist. Berücksichtigen Sie hierbei die zuvor aufgestellten Reaktionsgleichungen für das Gleichgewichtssystem.

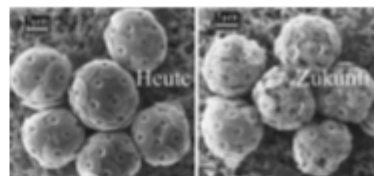


Abbildung 2: Coccolithophoriden unter heutigen Bedingungen (links) und in einem versauerten Ozean durch hohem CO_2 -Gehalt (rechts).

5. Wie wirkt sich die Versauerung des Meeres auf die Larvenstadien der Seeigel aus?

6. Bei dem folgenden Diagramm handelt es sich um eine Auswertung des SCRIPPS (Institut of Oceanography, UC. San Diego). Schätzen Sie ab, wie sich die Entwicklung der CO₂-Konzentration der letzten 100 Jahre in der Atmosphäre auf den Zustand der Weltmeere auswirken wird.

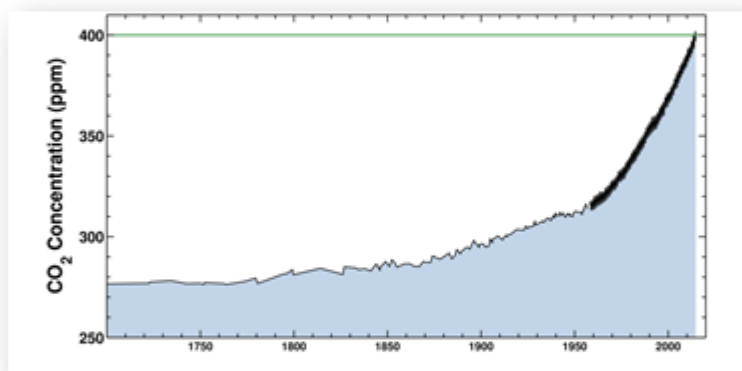


Abb. 2: CO₂-Konzentration der Atmosphäre, gemessen am Mauna Loa (aktiver Vulkan auf der Hauptinsel von Hawaii).

Quellen:



Zitat: Kieler Exzellenzcluster "Ozean der Zukunft", online unter: http://www.futureocean.org/de/cluster/ueberblick/A1_ozeanversauerung.php (Stand: 03.12.2014); **Abb.1:** Maïke Nicolai (GEOMAR), online unter:

http://www.geomar.de/typo3temp/pics/2010-06-02_Spitzbergen-Mesa-4_MaïkeNicolai_118cd456d.jpg (Stand: 03.12.2014);

Abb.2: Foto: Ulf Riebesell, IFM-GEOMAR (Quelle: <http://www.geomar.de/news/article/bioacid-kick-off/>, Stand: 17.11.2014); **Abb. 3:** https://scripps.ucsd.edu/programs/keelingcurve/wp-content/plugins/sio-blumoon/graphs/co2_800k_zoom.png (Stand: 17.11.2014)

Working Materials Study II

Experiments



OSTSEE DER ZUKUNFT
Erwärmung

Die Erwärmung der Ostsee

Der Ostseeraum hat sich im vergangenen Jahrhundert bereits um etwa 0,85 °C erwärmt. Damit liegt die Erwärmung leicht über dem weltweiten Durchschnitt. Computermodelle zeigen, dass die Lufttemperaturen Ende des Jahrhunderts im Vergleich zu heute je nach Berechnungsmodell um 4 – 8°C im Winter und 1 – 4°C im Sommer steigen werden. Damit einher geht eine Erhöhung der Wassertemperatur um 2 – 4°C (siehe Abb.1).

Dies führt zu einer Reduzierung der jährlichen Eisbildung um 50-80% und zu einer generellen Zunahme der Niederschläge. Mit der Erwärmung hat sich auch die Häufigkeit extremer Temperaturen verändert. In einem Jahr gibt es heute an der deutschen Ostseeküste etwa zehn Sommertage (wärmer als 25 °C) mehr und etwa 20 Frosttage weniger als in den 1950er Jahren.

Die Veränderungen im Ostseeraum sind regional unterschiedlich: Die reduzierte Eisbildung im Norden sorgt für eine stärkere Erwärmung als in der südlichen Ostsee.

(Quellen: Helmholtz-Zentrum Geestacht, 2012; Meier et al., 2012)

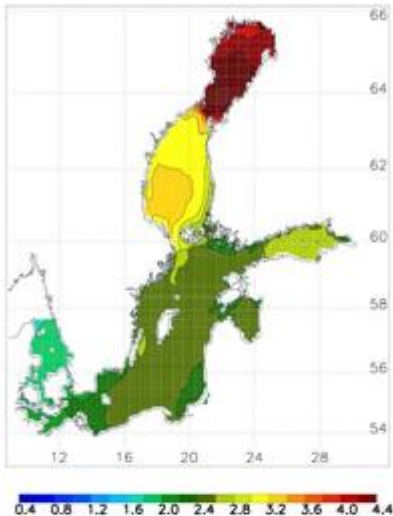





Abbildung 1 Entwicklung der sommerlichen Oberflächentemperatur (JJA) in °C zwischen 2069 - 2098 und 1978 - 2007; Quelle Meier et al. 2012)

Der Blasentang – einzige Großalge der Ostsee



Der Blasentang gehört zu den **Braunalgen** und wird im lateinischen *Fucus vesiculosus* genannt. Er ist ein sehr bekannter Vertreter der Ostseeflora, welcher in der Brandungszone vor allem auf festem Untergrund wie Steinen, Felsen oder Holz wächst.

Die mehrjährige **Großalge** erreicht eine Länge von bis zu einem Meter und weist die charakteristischen Gasblasen auf, welche zum Auftrieb im Wasser dienen. Der Blasentang hat eine besondere Bedeutung für die Ostsee, da er das Habitat für eine Vielzahl von Organismen darstellt und die einzige Großalge der gesamten Ostsee ist.



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1

Versuch: Messung der temperaturabhängigen Sauerstoffproduktion

Forschungsfrage:

Materialien:

- Blasentang
- 3 Winklerflaschen mit O₂-Spots
- Eis
- Thermometer
- Wärmeplatte
- Fibox 4 (O₂-Messgerät)
- Stoppuhr
- Aquarienlampe
- Schere

Durchführung:

1. Der Blasentang wurde für 24 Stunden bei unterschiedlichen Temperaturen gehältert. Schneidet je Ansatz 10cm lange Spitzen des Blasentangs ab. Achtet darauf, dass alle ungefähr gleich groß sind!
2. Füllt die drei Steilbrustflaschen randvoll mit Ostseewasser und gebt die Blasentangspitzen in je eine Flasche. Verschließt die Flaschen mit den Thermometer-Stopfen.
3. Erwärmt die eine Flasche auf 30°C und kühlt die andere auf 12°C ab, die dritte bleibt bei der ursprünglichen Temperatur.
4. Messt in allen Flaschen den Sauerstoffgehalt mit dem Fibox 4. Tragt die Ergebnisse in die Tabelle ein.
5. Stellt nun die Ansätze unter die Lampe für 30 Minuten. Achtet darauf, dass jede Flasche ausreichend viel Licht erhält!
6. Nach 30 Minuten könnt ihr den Sauerstoffgehalt des Blasentangs in den unterschiedlichen Ansätzen messen. Tragt die Ergebnisse in die Tabelle ein.

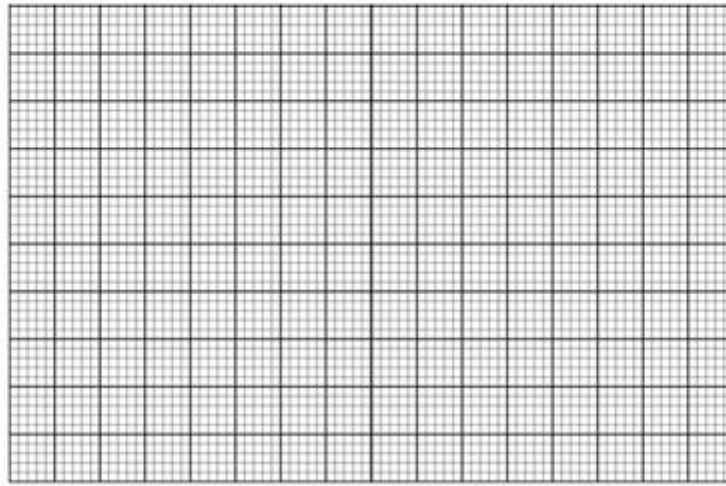
Ergebnisse:

Zeitpunkt 0		Nach 30 Minuten		O ₂ -Produktion in mg/l
Temperatur in °C	O ₂ -Gehalt in mg/l	Temperatur in °C	O ₂ -Gehalt in mg/l	



Aufgabe 1

Erstelle eine Kurve der Fotosyntheserate in Abhängigkeit zur Temperatur.



Aufgabe 2

Beschreibe die Auswirkung erhöhter Wassertemperatur auf die Fitness des Blasentang.

Aufgabe 3

Erkläre was die geringere Fitness des Blasentang für das Ökosystem Ostsee bedeutet.



Die Ozeanversauerung

Durch die Verbrennung fossiler Energieträger kommt es zu einem Anstieg des Kohlenstoffdioxidgehaltes in der Atmosphäre. Seit Beginn der Industrialisierung haben die Weltmeere knapp die Hälfte des Kohlenstoffdioxids (CO_2) aufgenommen. Im Meer reagiert CO_2 zu Kohlensäure und Hydrogenkarbonat, wodurch der pH-Wert des Wassers sinkt. Das Meer wird saurer. Korallen, Muscheln und Schnecken aber auch kleinere Organismen, die ihre Schalen aus Kalk aufbauen, können sich im saureren Wasser nicht mehr wie bisher entwickeln. Dies hat weitreichende Folgen für das gesamte Ökosystem Ozean!

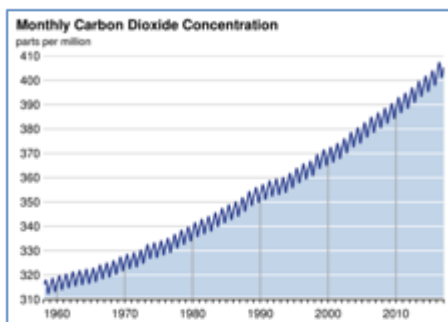


Abbildung 1 Entwicklung der atmosphärischen CO_2 -Konzentration 1960 - 2017

Versuch 1: Auflösen von Muschelschalen

Forschungsfrage

Materialien:

- Reagenzglas
- Porzellan Pistill
- Porzellan Mörser

Chemikalien:

- Salzsäure: $c(\text{HCl}) = 0.1 \text{ mol/L}$
- Muschelschalen



Schutzbrille, Handschuhe, Kittel nicht vergessen!

Durchführung:

1. Zerreibt die Muschelschalen in dem Mörser bis ein Pulver entsteht.
2. Gebt das Muschelschalen-Pulver in das Reagenzglas und fügt ca. 4 mL der $c = 0.1 \text{ mol/L}$ Salzsäure hinzu.

Beobachtung:

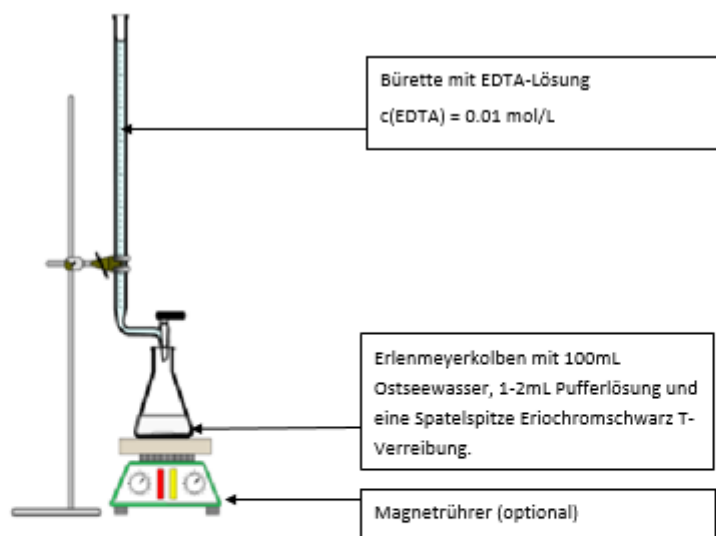
Versuch 2: Bestimmung der Calciumionenkonzentration*Materialien:*

- Kleines Aquarium
- Bürette, 25ml
- Stativ und Bürettenhalter
- Spatel
- evtl. Magnetrührer
- Erlenmeyerkolben
- Soda Stream und Flasche

*Chemikalien:*

- Ostseewasser
- EDTA (0.01 mol/L)
- Eriochromschwarz T-Verreibung
- CO₂
- Miesmuscheln
- Pufferlösung (pH 10):
Ammoniumchlorid-Ammoniak

Schutzbrille, Handschuhe, Kittel nicht vergessen!

Aufbau:

Durchführung

1. In das Aquarium wird Ostseewasser und zerriebene Muschelschale gegeben. Ermittelt den pH-Wert der Probelösung.
2. Es werden mit einer Vollpipette 50mL der Probe zur Calciumbestimmung entnommen und in den Erlenmeyerkolben gegeben.
3. Befüllt die Bürette wird mit EDTA-Maßlösung und stellt diese auf 0 ein. Nun wird die Probe mit 2mL Pufferlösung versetzt und eine Spatelspitze Eriochrom T-Verreibung hinzugegeben.
4. Titriert die Probelösung im Erlenmeyerkolben mit 0.01 molarer EDTA-Lösung bis zum Farbumschlag. Das Ende der Titration ist erreicht, wenn der Farbumschlag von purpur zu blaugrün erfolgt.
5. In das Aquarium werden nun zwei Liter CO₂ haltiges Wasser (Soda Stream) hinzugegeben. Dabei muss darauf geachtet werden, dass das Wasser vorsichtig hinzugegeben wird, da die Muschelstücke am Beckenboden nicht aufgewirbelt werden sollen. Ermittelt auch hier wieder den pH-Wert.
6. Die Titration wird mit der zweiten Wasserprobe wiederholt.
7. Nach den Titrationen werden die Lösungen in den Säuren/Schwermetall-Abfall gegeben.

Hintergrundinformationen zur Titration:

Die Titration ist ein Verfahren der **quantitativen Analyse** in der Chemie. Ein bekannter Stoff (hier: Calcium), dessen Konzentration unbekannt ist (**Probelösung**), wird in einer gezielten chemischen Reaktion mit einer **Maßlösung** (hier: EDTA) umgesetzt, deren Konzentration genau bekannt ist. Das Volumen der verbrauchten Maßlösung wird dabei gemessen und anhand der Stöchiometrie die unbekannte Konzentration der Probelösung berechnet.

EDTA ist ein **Komplexbildner**: es reagiert bevorzugt mit den Calciumionen der Lösung und bildet einen Komplex. Sobald alle Calciumionen mit einem EDTA-Molekül gebunden sind, wird die Lösung blaugrün. EDTA bindet sich nicht mit festem Calciumcarbonat sondern nur mit den Calciumionen, die im Wasser gelöst sind.

Beobachtung:

	pH-Wert des Ostseewassers	Verbrauch von EDTA bis zum Farbumschlag
Probe 1		
Probe 2		

Aufgabe:

Durch die erhöhte CO_2 -Konzentration, sinkt der pH-Wert der Modell-Ostsee. Aus dem ersten Versuch wisst ihr, dass durch Säure Carbonate (wie die Muschelschale) gelöst werden.

Erkläre warum die Kalkbildung bei erhöhtem CO_2 -Gehalt der Atmosphäre erschwert ist. Berücksichtige hierbei die zuvor aufgestellte Reaktionsgleichung für das Gleichgewichtssystem.

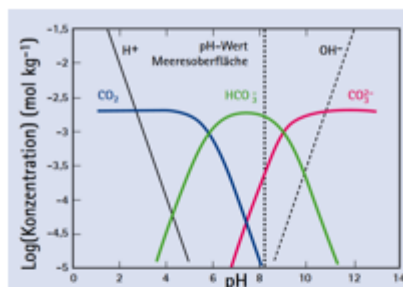
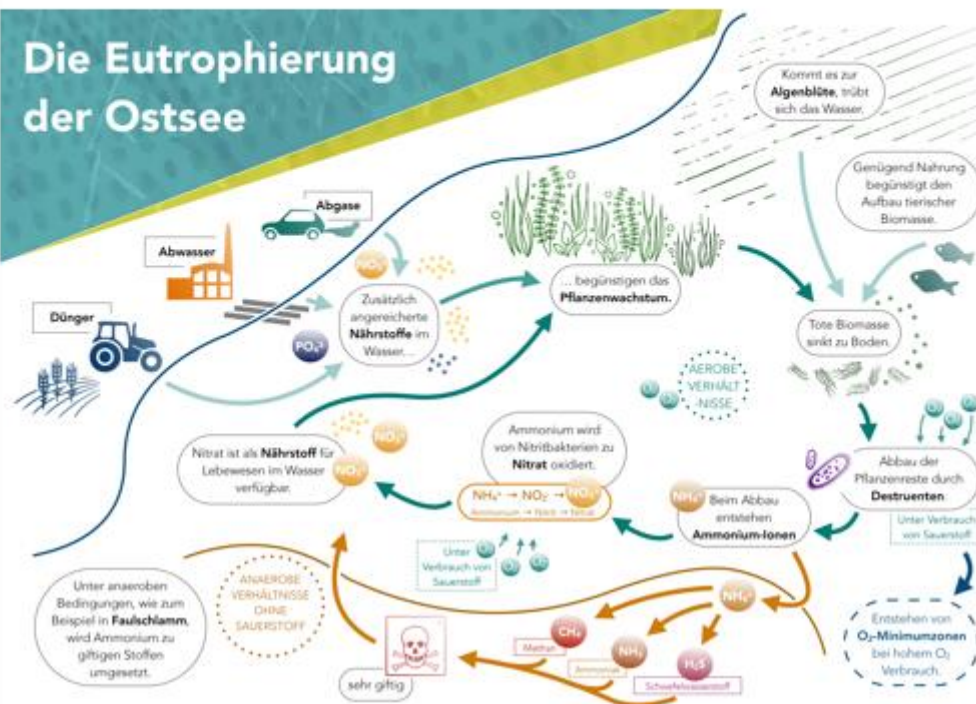


Abbildung 2 Mit sinkendem pH-Wert steigt der Anteil des gelösten CO_2 . Der Anteil der Karbonationen nimmt ab.
Quelle: BIOACID, 2012

Wirksamkeit eines Experiments: Realitätsbezug vs. Showeffekt

In den zwei Experimenten wurden die Auswirkungen des veränderten pH-Wertes auf kalkbildende Organismen analysiert, wobei die Effekte recht unterschiedlich waren. Nehmt die Rolle eines Wissenschaftlers ein, der zeitnah einen Vortrag über die Ozeanversauerung vor einem durchschnittlichen Publikum halten soll. Würdet ihr eins der beiden durchgeführten Experimente zeigen?

Die Eutrophierung der Ostsee



Chlorophyll – Der grüne Pflanzenfarbstoff

Chlorophylle sind natürliche Farbstoffe in den **Chloroplasten** von Organismen, die Fotosynthese betreiben. Die **Fotosynthese** ist der bedeutendste biogeochemische Prozess der Erde und zugleich einer der ältesten. Dabei werden aus anorganischen Baustoffen (CO₂ und H₂O) mit Hilfe der Lichtenergie organische kohlenstoffverbindungen (Kohlenhydrate, C₆H₁₂O₆) und Sauerstoff (O₂) hergestellt.



Die Hauptaufgabe der Chlorophylle bei der Fotosynthese ist die Fixierung der Lichtenergie (**Lichtabsorption**). Dabei werden rote und blaue Anteile des Sonnenlichts sehr stark absorbiert, während grüne Bereiche des Spektrums hingegen wenig bis gar nicht aufgenommen werden (**Grünlücke**). Die grüne Erscheinung der Blatt- und Algenpigmente für das Auge ist auf diese Absorptionseigenschaften zurückzuführen.

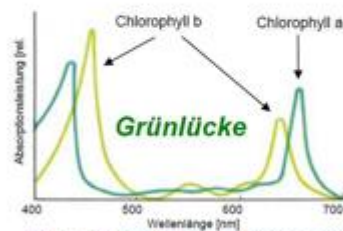


Abb. 2 Die Grünlücke, Quelle: gorgonien-lexikon

Versuch: Untersuchung des Chlorophyll-Gehaltes durch Fotometrie

Zur Untersuchung der Eutrophierung in einem Gewässer wird die Biomasse des Phytoplanktons als biologische Kenngröße herangezogen. Um diese zu bestimmen, wird die Konzentration des Chlorophylls fotometrisch bestimmt.

Forschungsfrage:

Materialien:

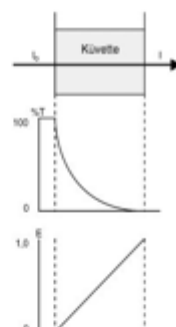
- Fotometer
- Küvetten
- Wasserproben
- Dest. Wasser

Was ist ein Fotometer?

Ein Fotometer ist ein Gerät, welches die Lichtabsorption bestimmter Lösungen misst. Funktion: Eine Quelle sendet sichtbares Licht durch eine Küvette mit wässriger Messlösung. Beim Durchtritt der Lichtstrahlen durch die Messlösung wird ein Teil des eingestrahnten Lichts durch die Moleküle in der Lösung absorbiert. Das durchgehende Licht wird in einer lichtempfindlichen Zelle gemessen (Transmission, %T). Die Lichtabsorption kann nicht direkt gemessen werden und muss daher aus der Transmission errechnet werden:

$$E = \log_{10} (100 / \%T_{\text{Trans}})$$

Beziehung zwischen Lichtintensität (I , I_0),
Transmission (T) und Extinktion (E)

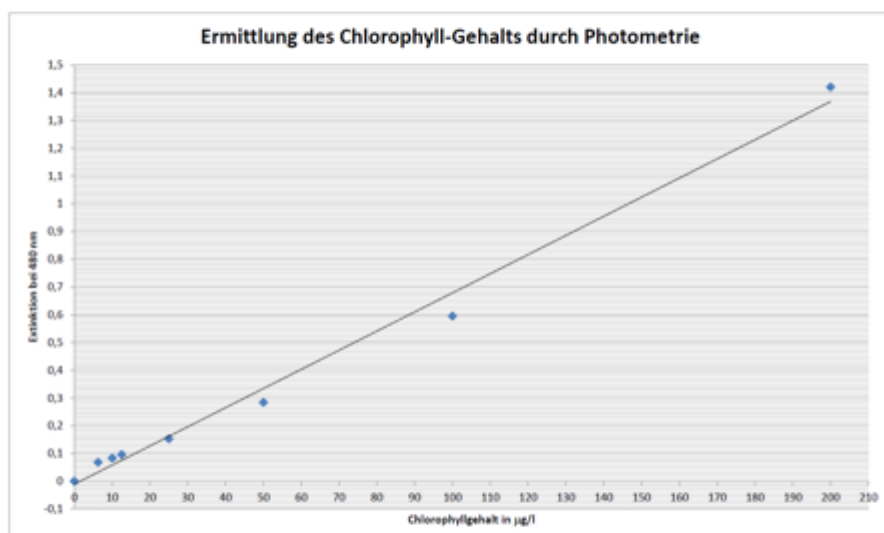
*Durchführung:*

1. Schaltet das Fotometer an und wählt die Wellenlänge 480nm (blau).
2. Füllt die erste Küvette mit dest. Wasser und führt einen Nullabgleich durch. Dafür stellt ihr die Küvette in das Fotometer und drückt CAL (=calibration).
3. Wascht die nächsten Küvetten mit dem Probenwasser aus und füllt sie mit diesem. Achtet darauf, dass die Proben gut durchgemischt sind.
4. Trocknet die Küvetten ab und stellt sie nacheinander in den Lichtschacht des Fotometers.
5. Nun könnt ihr die Transmissionswerte ablesen. Tragt sie unten ein und berechnet die Extintionswerte.

Beobachtung:

	Transmissionswert	Extinktionswert
Probe Au		
Probe Badestrand		

Mit Hilfe der Eichkurve kannst du dem Extinktionswert einen entsprechenden Chlorophyll-Wert zuweisen.



Chlorophyll-Gehalt Probe Au: _____ µg/l

Chlorophyll-Gehalt Probe Badestrand: _____ µg/l

Auswertung:

Bewerte mit Hilfe dieser Tabelle den Eutrophierungszustand der Wasserproben aus der Kieler Förde.

Gehalt Chlorophyll a in µg/L	Trophiestufe	Bewertung
< 1 – 4	oligotroph	unbelastet
3 – 8	mesotroph	gering belastet
7 – 30	eutroph	mäßig belastet
25 – 50	eu- bis polytroph	kritisch belastet
50 - 100	polytroph	stark verschmutzt
> 100	poly- bis hypertroph	sehr stark verschmutzt
	hypertroph	übermäßig verschmutzt

Aufgabe

Erkläre inwiefern sich die Eutrophierung auf das Wachstum von Epiphyten auswirkt und welche Auswirkungen das für die Ostsee hat.



Simulation



<https://ostsee-der-zukunft.experience-science.de/start/aufgaben.html>

DECLARATION OF ETHICAL CONDUCT

I hereby declare that the work presented in this dissertation, apart from the advice given by my supervisors, is my own in both format and content. Manuscripts I and III (Section 4 and Section 6) are submitted for publication at a peer reviewed scientific journal. Manuscript II is written and will be submitted at a peer reviewed scientific journal as soon as possible. This is my first dissertation and the contents have not been used in any prior attempts to obtain a PhD. The dissertation complies with the standards for good scientific practice as proposed by the German Research Foundation. I have not been deprived of an academic degree.

Kiel, _____

Johanna Tana Krüger