Climate Change Education in Physics Teaching

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Abstract. Climate change is one of the most pressing issues of our time. Therefore, physics education should help students address this issue. This symposium delves into approaches to integrating climate change education within physics teaching. The first contribution explores greenhouse effect learning environments in secondary education. The second talk presents the evaluation of climate change tutorials. The third contribution introduces a critical thinking test regarding climate change. The last contribution delves into teacher attitudes towards assessing climate protection measures. These contributions collectively offer insights into pedagogical strategies, assessment methodologies, and educator perceptions crucial for effective climate change education in physics.

Introduction

Climate change is one of the most significant and pressing global issues of our time [1]. Therefore, it is essential to ensure that students are equipped with knowledge, attitudes and skills needed to understand and address this complex problem [2]. Consequently, there is a growing interest in integrating climate change education into science teaching in schools [3, 4], not only from a research-perspective but also according to framework documents [2]. Physics education should therefore also address climate change from various perspectives and foster climate literacy in students. In this symposium, we address various aspects that relate to factors facilitating climate literacy, spanning from school students to future and in-service teachers. We present research findings stemming from test-instruments, questionnaires and the evaluation of interventions to paint a broad picture of possible pathways for integrating climate change education into physics teaching.

Climate Literacy

According to the USGCRP [2], climate literacy is an understanding of one’s own influence on climate as well as climate’s influence on each individuum. Following this, climate literacy can furthermore be divided into four dimensions:

1. An understanding of the essential principles of Earth’s climate system.
2. Knowledge how to assess scientifically credible information about climate.
3. Communicating about climate and climate change in a meaningful way
4. Making informed and responsible decisions with regard to actions that affect climate.

Therefore, when it comes to climate education in physics education, it should address these four dimensions. However, in order to ensure effective climate change education, several prerequisites need to be met: Among others, teachers need to have the necessary competence to implement meaningful climate change education [5–7]. For example, when it comes to communicating about climate change, teachers need to know how to purposefully organize classroom discussions that do not only address physics aspects, but also political or ethical issues [8]. Furthermore, teachers need to be supported in this endeavour by providing them with evidence-based teaching materials [9].

Contributions in this symposium

In this symposium, we want to address these issues and provide examples of how integration of climate change education in physics education can be fostered according to the climate literacy principles listed above. Regarding a conceptual understanding of climate change, the first contribution addresses the development of a learning environment regarding the greenhouse effect for secondary education. In the second contribution, the evaluation of so-called "climate change tutorials" [10] is presented. These two contributions hence address dimension one. The third contribution focuses on the second and fourth dimension of climate literacy and presents a test instrument that measures student's critical thinking skills in the context of climate change. Finally, the fourth contribution covers dimensions three to four and presents a study investigating teacher attitudes towards assessing climate protection measures.

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Research-based development of a learning environment on the greenhouse effect for lower secondary education

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Abstract. This study addresses the urgent need for climate change education by focusing on the development of an effective learning environment about the greenhouse effect for lower secondary education. Within the paradigm of design-based research, knowledge from learning theories and empirical findings is transferred into the learning environment using design conjectures and design criteria. In addition to the design of an effective learning environment, student learning about the greenhouse effect will be explored. Preliminary findings and the first version of the learning environment will be presented at the conference, shedding light on implications for future design cycles and domain-specific learning theories.

Focus of the study

This contribution focuses on conceptual understanding of essential principles of Earth's climate system, one of the dimensions of climate literacy according to the USGCRP [1]. One of the central physics concepts for comprehending climate change is the greenhouse effect [2]. Therefore, addressing alternative ideas about the greenhouse effect in the classroom is essential to break the cycle of knowledge gaps and inactivity [3]. Employing a conceptual change perspective [4], we aim to create a learning environment on the greenhouse effect. To potentially reach all students, conceptual understanding of the greenhouse effect should be addressed in compulsory education. Accordingly, the learning environment focuses on lower secondary education. Using the paradigm of design-based research allows us to simultaneously develop an effective learning environment and explore learning and teaching dynamics within it [5]. Accordingly, our second goal is to enhance domain-specific learning theories.

Research questions

The following research questions guide our study:

1. What can an effective learning environment on the greenhouse effect for lower secondary education look like?
2. How do students interact with the learning environment?
3. How does students' conceptual understanding of the greenhouse effect evolve during their interaction with the learning environment?

Research design and methods

In design-based research, we follow Obczovsky et al.'s [6] approach. We start with theory-based assumptions, called design conjectures, about teaching on the greenhouse effect. These rely on learning theories as well as empirical evidence and aim to transfer knowledge effectively to the context at hand. For example, two design conjectures are based on domain-specific teaching-learning theories about electromagnetic radiation [7] and optics [8].

Design criteria, derived from these conjectures, guide the embodiment of the learning environment. This includes tools, materials, structures, and discursive elements [9]. The initial learning environment was designed along these criteria. To further support individual design decisions, we conducted a survey among 8th grade students (until April: N = 150) and adults (N = 100) concerning the visual representation of infrared radiation, absorption and molecules. To investigate and analyse individual student learning processes, the learning environment will be tested in teaching experiments [10] during the summer semester 2024. Based on the analysis of the teaching experiments, design conjectures and design criteria will be expanded and refined, and the learning environment will be re-designed. The process repeats to enhance the learning environment and insights into domain-specific learning theories iteratively.

Preliminary and anticipated findings

At the conference, we will present the design conjectures and design criteria, the first version of the learning environment, as well as data from the survey and the first implementation in teaching experiments. Results from the survey showed that ideas from domain-specific teaching-learning theories about optics and radiation are fruitful for the context of the greenhouse effect. For example, the visual representation of the interaction of radiation and matter as adopted from those theories is perceived as helpful by learners. Further analysis of the learning environment will be presented based on individual student learning processes in the teaching experiments.

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Development and Evaluation of “Tutorials in Climate Change”

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Abstract. Climate change is one of the most pressing challenges facing humanity. In order to foster student learning about climate change, high quality lessons necessary. To provide effective lessons, teachers’ own conceptual understanding as well as knowledge about typical learning difficulties are basic prerequisites. To address this, we developed so called *Tutorials in Climate Change* to support future teachers’ conceptual understanding of climate change. The evaluation with over 50 pre-service teachers across three countries provides evidence for the effectiveness of the developed tutorials. We present the rationales and design of the tutorials as well as results of the evaluation.

Introduction

Climate change is one of the most pressing challenges facing humanity in the 21st century, with far-reaching implications for ecosystems, economies, and societies worldwide [1]. As the consequences of climate change become increasingly evident, there is a growing urgency to equip (future) generations with the knowledge and skills to address this complex issue effectively [2].

To reach this goal, when it comes to fostering conceptual understanding of the scientific principles underlying climate change among students, high quality teaching is pivotal. Therefore, teachers need to have corresponding knowledge and skills to provide high quality teaching [3]. Thereby, conceptual understanding of climate change from teachers themselves can be seen as one of the most fundamental basics, since profound content knowledge can be seen as prerequisite for the development of pedagogical content knowledge [4], which in turn is necessary to e.g. provide effective instructional explanations in classes [4]. Furthermore, research has shown that teachers’ knowledge of typical student learning difficulties also predicts student learning [5].

Hence, we argue that when it comes to teaching the scientific principles of climate change, teachers first and foremost need to develop their own conceptual understanding of climate change in addition to learning about typical learning difficulties, as previous research has shown that teachers often feel ill-prepared [6].

To address these needs, we developed ten so-called *Tutorials in Climate Change* [7] which can be used in teacher education programs, but also for secondary school teaching.

Rationales for the development of *Tutorials in Climate Change*

Several rationales guided the development of our tutorials. First, our tutorials address five different concept areas that were described as crucial for developing an understanding of climate change [8]: (1) our atmosphere, (2) the difference between weather and climate, (3) climate as a system, (4) the carbon cycle and (5) the greenhouse effect. Second, our tutorials follow a modified anchored instruction approach, since research has emphasized the importance of situating instruction in contexts that are meaningful [9]. Anchored instruction furthermore gives teachers and students the opportunity to work from a shared experience perspective. Third, we incorporated concept cartoons to support future teachers in overcoming their potential misconceptions and in turn also learn about typical learning difficulties from school students [10]. Finally, we designed the tutorials in such a way that they can also be used for teaching in upper secondary classes, so teachers are provided with similar learning experiences than their future school students.

Results of the Evaluation

We tested the *Tutorials in Climate Change* with N= 76 future physics teachers from Austria, Belgium, and Germany in a pre-post format. For the evaluation, we used a previously developed and validated climate change concept inventory [8]. Results thereby show that the future teachers positively develop their conceptual understanding of climate change ($t(150) = 5.1$, $p<.001$) with a large effect size (*d = 1.11)* and independent of the course they participated in ($F(71,3) = 1.4$, $p = 261$).

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Assessing Critical Thinking Skills in the Context of Climate Change

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Abstract. The young generation is strongly affected by the consequences of climate change. Therefore, they should be able to participate in corresponding debates and to make informed decisions based on critical thinking skills in this specific context. To evaluate critical thinking skills of high school and university students in the context of climate change a test instrument was developed. A total of 41 items were tested with 240 participants so far. The initial results are satisfactory. The test is appropriate for the population with good psychometric data. After some adaptation, the test will be re-tested with high school students.

Introduction and theoretical framework

Climate change should be addressed at the content level to gain “an understanding of the essential principles of Earth’s climate system” [1]. Conceptual understanding forms the foundation for dealing with a subject matter in depth, for being able to critically assess sources and making informed and responsible decisions in this domain-specific area [1].

However, as teenagers and young adults are no climate scientists, they should be able to analyse and evaluate the information they receive mainly from non-scientific and social media [2]. Climate change is a topic of public debate that combines complex areas of physics, such as the concentration of greenhouse gases in the atmosphere and the greenhouse effect [3]. Economic factors and political agendas with different goals also weigh in, evoking strong emotions among the discussants [4]. To live a self-determined and responsible life, students need to learn to critically question their own positions, solutions and approaches and to justify their own opinion [5]. This requires the ability of critical thinking. Halpern [6] defines critical thinking as “thinking that is purposeful, reasoned, and goal directed – the kind of thinking involved in solving problems, formulating inferences, calculating likelihoods, and making decisions”. She identifies five critical thinking skills [6]: verbal reasoning, argument analysis, hypothesis testing, likelihood and uncertainty, problem solving and decision making. In the complex topic climate change we focus on the five different concept areas that are covered in the concept inventory “CCCI-422” [3]:

Earth's atmosphere, climate as a system, the carbon cycle, the difference between weather and climate and the greenhouse effect.

Research goal

Given the importance of critical thinking in climate change, we developed a test instrument to assess the critical thinking skills among high school and university students on the topic of climate change, based on the Halpern framework [6] and the five CCCI-concept areas [3].

Methods and findings

Firstly, semi-structured interviews were conducted with high school students from Saxony and pre-service teachers at TU Dresden (N=16). The interviews were transcribed, categorized and analyzed using qualitative content analysis according to Kuckartz [7]. Based on the participants' answers, realistic distractors for test items were created which reflect known learner ideas [3, 8] and show frequently used argumentation patterns. The first version of the single-choice test "CTCC" ("Critical Thinking in Climate Change") features 41 items. The test was administered using two booklets each containing 26 items, anchored through 11 joint items, with students at four different universities and with high-school students of 10^{th} and 11^{th} grade at two high schools, resulting in a sample size of N = 240. The average time needed to complete the test was around 40 minutes. The test data were analyzed using Rasch data analysis [9].

The initial results are satisfactory, with a Cronbach's alpha of 0.78, a high item reliability of 0.96 and a person reliability of 0.85. For the first implementation, the cut-off values of 0.5 and 1.5 for infit and outfit values were defined, which can be regarded as good enough for the measurement [10]. The item-person map shows the good targeting of the test, with the middle of the item difficulty matching the middle of the respondents' abilities and the test covers the population quite well.

Conclusion

The first analysis shows that the test functions satisfactory, but some adaptations are needed. Further examination and Rasch analyses will be done to refine the test instrument and to re-test it. By assessing critical thinking skills in the context of climate change, it will be possible to create and evaluate specific teaching materials that address students' difficulties in this area.

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Teachers' Attitudes Towards Assessing Climate Protection Measures

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Abstract. Educating students to become climate-literate persons comprises informed and responsible decision-making with regard to actions that may affect climate. Teachers have different attitudes towards this aim. We investigated predictors of teachers‘ willingness and intention regarding the assessment of climate protection measures in physics classroom. Therefore, we used a questionnaire based on the Theory of Planned Behavior which was completed by 204 Austrian physics teachers. The results show strongest predictions by teachers' perceived necessity of the topic, and their self-efficacy in it. This implicates the consideration of perceived necessity and self-efficacy when developing a respective in-service teacher training course.

Introduction

Climate change and the climate crisis require extensive action, including the field of education [1]. Educating students to become climate-literate persons comprises informed and responsible decision-making with regard to actions that may affect climate [2]. The new Austrian curriculum for physics education in secondary high school addresses this dimension as students should be taught how to "classify measures to meet current aims of climate protection at a personal, regional and global level and discuss their implementation options" in 8th grade [3]. Teachers face different challenges on multiple levels when teaching this kind of socio-scientific decision-making [4]. Therefore, this contribution aims at investigating hindering and facilitating factors of teachers‘ willingness and intention about assessing climate protection measures in physics education.

Theoretical framework and research question

The research is based on the Theory of Planned Behavior (TPB). According to TPB, teachers' intention to teach a certain topic depends on the attitudes towards this behavior, the subjective norms, and the perceived behavioral control [5]. As ceiling effects are determined for intention in teaching a mandatory topic, Heuckmann et al. [6] introduced the additional construct "willingness" which means teaching the topic while the imagination of having free choice [6]. Also, Heuckmann et al. [6] split up attitudes and perceived behavioral control into two subscales each. Based on this theoretical framework, we follow the research question "To what extent do attitudes (towards the perceived burden and necessity), subjective norms, as well as perceived behavioral control (regarding the autonomy and self-efficacy) predict teachers' intention and willingness to teach the assessment of climate protection measures in 8th grade physics classroom of secondary high school?". To the authors‘ current knowledge this is the first research linking climate change education and in-service physics teacher education with the Theory of Planned Behavior. Thereby, we aim at an evidence-based development of in-service teacher training.

Methods

We used an online questionnaire, for which constructs and items were adapted from an existing questionnaire from Heuckmann et al. [6]. 204 in-service physics teachers in Austria completed the questionnaire between October and December 2023. For each construct we conducted a Rasch analysis to check psychometric properties and to calculate teachers' measures [7,8]. After validating the scales, we conducted a multiple regression analysis from attitudes (two subscales), subjective norms and perceived behavioral control (two subscales) on intention and willingness.

Results

Our analysis shows significant results for attitudes towards the perceived necessity (β = .71, <.001), subjective norms (β = .37, <.001) and perceived self-efficacy (β = .60, <.001) on teachers' intention to teach the assessment of climate protection measures. The scales explained 51.2% of variance in intention. Attitudes towards the perceived burden and the perceived autonomy are not significant predictors for teachers' intention. Teachers' willingness is predicted significantly by attitudes towards the perceived necessity (β = .42, <.001), subjective norms (β = .32, <.001), perceived self-efficacy (β = .25, <.001) and perceived autonomy (β = .23, <.01). The variables explained 54.1% of variance in willingness. Attitudes towards the perceived burden to assess climate protection measures are not significant predictors of teachers' willingness.

Conclusion

The results show strongest influence of perceived necessity on teachers' willingness and self-efficacy on teachers' intention to discuss climate protection measures. This is an important contribution for developing respective teacher training courses, as the results suggest emphasizing the necessity of the topic and to foster teachers' perception about their own ability to teach it. Further research should focus on investigating specific teaching' beliefs underlying the constructs of the Theory of Planned behavior, especially regarding the necessity and self-efficacy.

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