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How learning about climate change affects intention and willingness to teach: a pre–post study with physics pre-service teachers

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Climate change education can act as a social tipping element that accelerates transformative change towards stabilizing Earth's climate by 2050. As the global climate crisis intensifies, it is increasingly important for teachers to incorporate climate change topics into their teaching. This pre-post study investigates how N = 71 physics pre-service teachers' (PST) conceptual understanding of climate change is related to their intention and willingness to teach the topic. We applied an extended Theory of Planned Behavior (TPB) model and conducted multigroup path analysis to examine how attitudes, subjective norms, and perceived behavioral control predict physics PSTs' teaching intentions. The study utilized a pre-post approach, analyzing changes after an intervention designed to enhance climate change understanding. Findings indicate that conceptual understanding significantly predicts self-efficacy and attitudes. Post-intervention, the relationships within the TPB model mainly remained consistent, with an amplified effect of conceptual understanding on self-efficacy and attitudes and an additional direct effect on the physics PSTs' willingness to teach about climate change. The results underscore the importance of targeted educational interventions in improving teachers' confidence and attitudes toward teaching climate change by fostering their understanding of climate change. These findings highlight the need for comprehensive teacher education programs to effectively prepare educators for climate change instruction.

KEYWORDS

climate change education, pre-service teachers, theory of planned behavior, conceptual understanding, intention to teach

1 Introduction

As the global climate crisis intensifies (Eyring et al., 2021), it is crucial that science teachers integrate climate change as a topic into their teaching. However, the quality and depth of climate change education varies significantly across different educational systems (Bhattacharya et al., 2021). For example, Herman et al. (2017) found considerable variation in the integration of climate science into curricula, with some students receiving comprehensive instruction while others encounter only superficial coverage. This imbalance can result from both structural framework conditions (such as syllabi or national education frameworks) and teachers' personal hesitance to integrate climate change education, leading to varied levels of understanding among students (Wildbichler et al., 2025a). However, due to the urgency of an intensifying climate crisis, we think it is important that teachers address climate change education regardless of whether it is a mandatory part of the syllabus, as students need the scientific understanding to respond to and act upon its far-reaching societal impacts.

Although extensive research exists on the challenges teachers face in implementing climate change education, few studies utilize well-founded theoretical approaches regarding implementation antecedents. Even fewer apply pre-post designs or investigate teachers' conceptual understanding of climate change as a predictor for teaching it. This study aims to address these gaps by examining the role of physics pre-service teachers' (PST) conceptual understanding of climate change in their willingness and intention to teach the subject. We rely on the Theory of Planned Behavior (TPB) to explain the factors influencing physics PSTs' intentions and willingness to teach about climate change.

Before stating our research questions, in the following sections, we will review previous research on teachers' intentions to teach about climate change, challenges in implementing climate change education, and the application of the Theory of Planned Behavior.

2 Teachers' understanding of climate change

In the context of secondary science education, effective climate change education relies on teachers' professional competencies (Blömeke et al., 2015), including their content knowledge (Kulgemeyer and Riese, 2018) about the scientific principles underlying climate change. Studies consistently demonstrate that teaching about climate change entails a whole group of challenges, including gaps and misconceptions in teachers' climate science knowledge, which significantly hinder their effectiveness in teaching this vital topic (Boon, 2010; Lambert et al., 2012; Liu et al., 2015; Lombardi and Sinatra, 2013; Plutzer et al., 2016; Ratinen, 2013; Apollo and Mbah, 2021; Bossér et al., 2015; Breitenmoser et al., 2024; Liu and Roehrig, 2019; Nation and Feldman, 2021; Winter et al., 2022).

For instance, although not all of them were science PSTs, Boon (2010) found that Australian PSTs shared many rudimentary or scientifically incorrect understandings of key climate change concepts with the general public. Common misconceptions included confusing weather with climate and incorrectly attributing climate change to the depletion of the ozone layer. These are some common ideas that are alternative to the scientific understanding also demonstrated by school students (Wildbichler et al., 2025a). Similarly, Higde et al. (2017) identified substantial gaps in the knowledge of Turkish PSTs, highlighting the need for more comprehensive training regarding climate change education. Herman et al. (2017) assessed secondary science teachers' knowledge and teaching practices in Florida and Puerto Rico, discovering that many held incorrect beliefs about the causes and consequences of climate change, which negatively impacted their teaching efficacy.

Moreover, Liu et al. (2015) found that in-service teachers' alternative conceptions and lack of understanding hindered effective instruction. Plutzer et al. (2016) highlighted that many U.S. science teachers possess an insufficient grasp of the scientific principles underlying climate change, which may hinder their ability to teach it effectively. Similarly, Lombardi and Sinatra (2013) found that teachers' emotions about climate change, combined with limited knowledge, affect their teaching effectiveness and how students perceive the topic. Extending these findings, Borgerding et al. (2024) show that while many secondary science teachers address at least some climate justice issues and actions, they tend to frame climate change narrowly as a global physical-science problem, rarely emphasize collective or sociopolitical dimensions, and often cite low perceived agency, fear of controversy, and insufficient content knowledge as barriers to broader instruction. Breitenmoser et al. (2024) complement these findings by highlighting how pre-service teachers' beliefs about the controversial nature of climate change and their perceived need to remain politically 'neutral' shape their willingness to teach it. The authors found that fears of appearing biased, concerns about parental backlash, and perceived lack of pedagogical content knowledge led many participants to adopt a neutral stance and to avoid engaging students in controversial discussions. This suggests that insufficient pedagogical content knowledge (for which content knowledge is a prerequisite, see e.g. Kulgemeyer and Riese, 2018) not only limits teachers' understanding but also reinforces beliefs and norms that supposedly reduce their perceived behavioral control and willingness to teach the topic comprehensively. These studies suggest that insufficient knowledge constrains how they frame climate change and the extent to which they feel capable of addressing it in their classrooms.

Hence, professional development programs and teacher education courses are critical in addressing these knowledge gaps. Scholars such as Beach (2023) and Oversby (2015) emphasize the need for enhanced professional development programs to equip teachers with the necessary knowledge and skills for effective climate change education. For example, Lambert et al. (2012) developed a targeted intervention that significantly improved both pre-service and in-service teachers' understanding of climate change by embedding specific content into an elementary science methods course.

All these studies imply that enhancing teachers' understanding of climate change increases their confidence and inclination to teach about it. Building on such findings, Williams (2019) applied Bandura's social cognitive theory and the Theory of Planned Behavior to model the relationships among U.S. science teachers' climate change efficacy, perceived behavioral control, subjective norms, environmental concern, and their climate-mitigating intentions and behaviors, demonstrating that these socio-cognitive factors are more predictive of intention and behavior than knowledge alone. In line with this, Fasching et al. (2025) found that in-service physics teachers' willingness and intention to teach climate action are strongly associated with perceived necessity, social pressure, and self-efficacy. While these studies begin to link teachers' beliefs and perceived control to their intentions, there remains a notable lack of systematic research that integrates teachers' climate-related with such TPB-related determinants (attitudes, norms, and perceived control) to explain their willingness and intention to teach about climate change. This study aims to address this gap by building on the TPB, which will be detailed in the following section.

2.1 Theory of planned behavior (TPB)

The TPB is a psychological framework used to predict individuals' deliberate behaviors based on their intentions (Ajzen, 1991). According to the TPB, intention is the most proximal and strongest predictor of behavior, and meta-analyses across the social and health sciences show that it typically explains 20–30% of the variance in behavior (Armitage and Conner, 2001; Hagger et al., 2002; Sheeran, 2002). Intention, in turn, is influenced by three conceptually distinct predictors: attitudes towards the behavior, referring to individuals' overall positive or negative evaluations of performing it; subjective norms, referring to perceived social pressures or expectations from significant others to perform or not perform the behavior; and perceived behavioral control, referring to individuals' perceptions of their capability and control over performing the behavior. These relationships are illustrated in Figure 1.

The TPB therefore provides a conceptually useful framework for researchers to identify which belief domains may act as barriers or levers for behavior change (Fishbein and Ajzen, 2011). It has therefore been widely applied in educational contexts to investigate teachers' intentions and behaviors. For example, TPB has been used to predict teachers' intention and behaviors in implementing inclusive education (Yan and Sin, 2014). Additionally, an extended TPB model was used to predict teachers' intention to use technology in teaching, based on their attitudes towards computer use and perceived behavioral control (Teo et al., 2016). TPB has also been used to explain elementary school teachers' intention to teach health education (Burak, 2002) and secondary school teachers' intention to teach about cancer (Heuckmann et al., 2020). More recently, Fasching et al. (2025) applied the TPB to in-service physics teachers' teaching about climate action and found that their willingness and intention to teach climate action were strongly predicted by perceived necessity of the topic, social pressure, and self-efficacy, showcasing the framework's usefulness for understanding teachers' climate-related instructional behavior.

However, Heuckmann et al. (2020) found ceiling effects for the intention of teaching cancer education, a compulsory curriculum topic, and introduced the willingness to teach as an additional, covarying construct to the intention.

Willingness captures the tendency to perform a behavior voluntarily and under conditions of free choice (Gerrard et al., 2008; Gerrard et al., 2005; Lee et al., 2016). In the context of mandatory behaviors, such as teaching the compulsory topic of climate change, willingness refers to whether the behavior would be performed by individuals under voluntary conditions and by free choice (Heuckmann et al., 2018, 2020; Fasching et al., 2025).

Building on these previous applications, this study uses the TPB to investigate pre-service teachers' intention and willingness to teach climate change, with a specific focus on how their conceptual understanding of climate change contributes to these motivational determinants.

2.2 Research questions and objectives

This study aims to address the following key research questions:

> RQ1: What is the role of conceptual understanding of climate change (CC) for the intention and willingness to teach about CC?

To address RQ1, we use a TPB model that we expanded with the PSTs' conceptual understanding of the scientific underpinnings of climate change and teaching experience regarding climate change and applied path analysis to explore how attitudes, subjective norms, and perceived behavioral control (self-efficacy) regarding teaching climate change predict PSTs' intention and willingness to teach the subject.

This model is based on previous research indicating that a solid grasp of subject matter enhances teachers' confidence in their ability to teach (Lambert et al., 2012; Liu et al., 2015). Teachers with a better understanding of climate change are likely to feel more prepared and capable of addressing student questions and misconceptions, which is supposed to boost their confidence and willingness to teach the subject (Plutzer et al., 2016). Additionally, a thorough understanding of climate change can positively influence teachers' attitudes towards teaching it by reducing perceived difficulty and enhancing the perceived importance of the topic (Lombardi and Sinatra, 2013). However, subjective norms are more influenced by external factors such as institutional policies and societal expectations than by individual knowledge (Ajzen, 1991).

> RQ2: How do physics pre-service teachers' intention and willingness to teach about climate change differ between a low-knowledge and a high-knowledge state resulting from working through tutorials in climate change?

To address RQ2, we employ the same extended TPB model as in RQ1 but adopt a pre-post approach to examine changes in this model following an intervention aimed at enhancing PSTs' conceptual

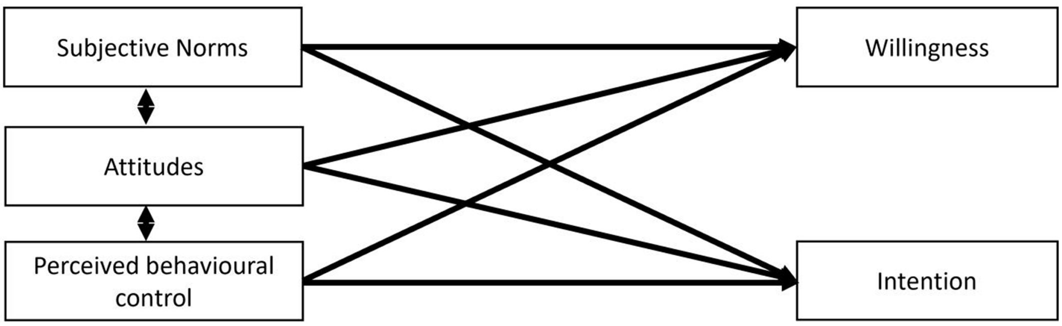

FIGURE 1
Theory of planned behavior framework (Ajzen, 1991), adapted based on Heuckmann et al. (2020).

understanding of climate change. We anticipate that the relationships within the TPB model will remain consistent, but the effect of conceptual understanding (in accordance with RQ1) will be stronger post-intervention. Since there is little previous research using an intervention, we approach this research question exploratively.

3 Materials and methods

3.1 Sample

Our sample consisted of $N = 71$ science PSTs (27 female, 1 diverse and 43 male) from a total of five different universities in Austria, Belgium and Germany, resulting in 142 measurements. On average, they were in their 8th semester ($M = 8.46$, $SD = 1.85$) of their teacher preparation studies. All PSTs participated voluntarily in this research and signed an informed consent about their participation. In Austria, students enroll in a 6-year study program to become physics teachers, while in Germany, they need to study 5 years. In Belgium, students take 2 semesters in the teacher preparation program, which usually follows a 4- or 5-year master program. Due to lack of teachers in these countries, some of the PSTs were already teaching in schools. Furthermore, using Single-Select questions, we asked the PSTs whether they thought climate change is happening and whether it is human made. Thereby, two of the PSTs indicated that they were not sure whether climate change existed or not and indicated that if so, it is mainly caused by nature, the others were sure that climate change is happening and caused by human activities. Eleven of the students had already taught about climate change in schools, eight had taught it once, two PSTs had taught about it twice and one PST had taught about it three times.

3.2 Design and materials

In the intervention to foster conceptual understanding of climate change, we used conceptual learning materials called *Tutorials in Climate Change* (Wildbichler et al., 2025b) that were developed in the project ENGAGING, co-funded by the European Union.

The name *tutorials* refers to an approach to deepen student understanding by providing learners with qualitative problems and opportunities to discuss and explain their reasoning. The original Tutorials were first developed and introduced by Lilian McDermott and Peter Shaffer in an introductory physics course as *Tutorials in Introductory Physics* (McDermott and Shaffer, 2002). It has been repeatedly reported that *Tutorials in Introductory Physics* have been effective in deepening student understanding (Benegas and Flores, 2014; Finkelstein and Pollock, 2005; Heron et al., 2004).

When developing *Tutorials in Climate Change* further ideas from physics education research, like using concept cartoons and anchored instruction, were incorporated (Wildbichler et al., 2025b).

In this study we used ten tutorials in total addressing five concept areas important for understanding the scientific underpinnings of climate change according to Schubatzky et al. (2023). These areas are: (1) Earth's atmosphere, (2) the difference between weather and climate, (3) climate as a system, (4) the carbon cycle, and (5) the greenhouse effect. A systematic literature review of research about student conceptions of climate change shows that alternative conceptions (i.e., conceptions that are alternative to the scientific understanding) about those concept areas are quite common (Wildbichler et al., 2025a). To address the most common alternative conceptions regarding these concept areas, the *Tutorials in Climate Change* are based on the results of a survey by Schubatzky et al. (2024b) among Austrian and German upper secondary students using a concept test covering the scientific underpinnings of climate change. The *Tutorials in Climate Change* focus on the concepts that were most difficult for students by addressing the most common alternative conceptions.

The tutorials use concept cartoons (Kabapınar, 2005) to introduce various alternative conceptions, but also the scientific concepts. These cartoons feature fictitious students discussing a topic, and learners evaluate their statements and explain their reasoning. This method aligns with the *Tutorials in Introductory Physics*, which also involve discussing and solving qualitative problems. To provide a shared context for the concept cartoons, *Tutorials in Climate Change* follow a modified anchored instruction approach (Kuhn and Müller, 2014), as research highlights the importance of situating instruction within meaningful contexts (Lovett and Shah, 2012).

Throughout each tutorial, learners then engaged with added information through various tasks. We thereby intended to foster conceptual change towards a scientific understanding. After completing these tasks, students revisited the concept cartoon to re-evaluate their initial assessments and reasoning. This final task allowed them to reflect on their learning and reinforce the new concepts. Learners worked in pairs on these tasks and were encouraged to discuss their ideas and reasoning in groups of two. Furthermore, at key points in the tutorials, learners checked and discussed their ideas with instructors.

Each of the tutorials in climate change took about 20–30 min to work through. The PSTs worked through five (Belgium) or ten (Austria, Germany) of these tutorials during a teacher education seminar at the respective universities.

In this study, we applied a pre-post design. Between the two measurements, all science PSTs participated in an intervention that focused on developing conceptual understanding of the scientific principles underlying climate change according to Schubatzky et al. (2024a) and Schubatzky et al. (2024b), resulting in approximately 3.5 h of intervention time. Pre- and post-test were administered at least a week apart.

3.3 Measures

We only used published and validated instruments to measure the investigated variables. For all variables we used methods of item response theory (IRT) (Boone et al., 2014) to estimate person parameters. For the test assessing the conceptual understanding of climate change using the CCCI-422 (Schubatzky et al., 2024b), we used a one-dimensional Rasch model where we coded one point for a correct answer and zero points for an incorrect answer. For the Likert-Scaled variables used for measuring the constructs within the TPB, we used rating scale models. For all estimations, we used the package tam (Robitzsch et al., 2019) within the software R (R Core Team, 2022). Using ideas of IRT, all raw scores are transformed into logits, which are reported in the results section. For teaching experience, we asked the PST's whether they already have teaching experience regarding climate change or no in a yes or no format.

All items except the test for conceptual understanding of climate change were adapted from the study of Heuckmann et al. (2018), where the wording of "cancer" was substituted with "climate change." All Likert-Scaled items ranged from 1 to 5, whereas the semantic differential scale was seven point. All items were administered in German in Austria and Germany, and in Dutch in Belgium. The same items were used both for the pre- and posttest.

3.3.1 Intention

For the intention to teach about climate change, we found an EAP person-reliability of 0.89, fit-values were all within an acceptable range (0.8 < Infit/Outfit<1.2). Table 1 shows the used items.

3.3.2 Willingness

For the willingness to teach about climate change, we found an EAP person-reliability of 0.89, fit-values were all within an acceptable range (0.8 < Infit/Outfit<1.2). Table 2 shows the used items.

3.3.3 Perceived behavioral control (self efficacy)

For the self-efficacy to teach about climate change, we found an EAP person-reliability of 0.68, fit-values where all within an acceptable range (0.8 < Infit/Outfit<1.2). Table 3 shows the used items.

3.3.4 Subjective norms

For the subjective norms about teaching about climate change, we found an EAP person-reliability of 0.81, fit-values were all within an acceptable range (0.8 < Infit/Outfit<1.2). Table 4 shows the used items.

3.3.5 Attitudes

For the attitudes towards teaching about climate change, we used a seven-point semantic differential. A semantic differential scale is a type of survey question that asks respondents to select a specific rating with the two endpoints of each scale being opposites. We found an EAP person-reliability of 0.67, fit-values were all within an acceptable range (0.5 < Infit/Outfit<1.5). Table 5 shows the used items.

3.3.6 Conceptual understanding of climate change

The test assessing conceptual understanding of climate change included five different domains: (a) Earths' atmosphere, (b) climate as a system, (c) carbon cycle, (d) difference between climate and weather and (e) greenhouse effect.

The single-select test consists of 36 items (see Table 6 for a sample item and Schubatzky et al., 2024b for the full test instrument). In previous studies, the testinterpretation was also analyzed for content validity (expert ratings), construct validity (dimensional analysis), discriminant validity (known groups), and cognitive validity (using a think-aloud study) (Schubatzky et al., 2023). In this study, we found an EAP-person reliability of 0.80 for this instrument. All fit-values of the items were within an acceptable range (0.8 < Infit/Outfit<1.2).

TABLE 1 Items used for measuring the PSTs intention to teach about climate change, translated from German.

Item
I intend to teach about climate change in the future.
I will teach about climate change in the future.
I plan to teach about climate change in the future.
I have strong intentions to teach about climate change.
Even if I encounter resistance, I have a strong intention to teach about climate change in the future.

TABLE 2 Items used for measuring the PSTs willingness to teach about climate change, translated from German.

Item
I would like to teach about climate change.
I have always been interested in teaching about climate change.
I have wanted to teach about climate change for a long time.
I would volunteer to teach about climate change.
I have the inner willingness to teach about climate change.
I feel the desire to teach about climate change.

TABLE 3 Items used for measuring the PSTs self-efficacy to teach about climate change, translated from German.

Item
I feel confident in teaching about climate change.
I feel prepared for teaching about climate change
I feel overwhelmed with teaching about climate change. (REVERSED)

TABLE 4 Items used for measuring the PSTs subjective norms about teaching about climate change, translated from German.

Item
People who are relevant to my future teaching find it important that I teach about climate change.
People who are important to my teaching would be disappointed if I did NOT teach about climate change.
People who are important to my teaching value me less when I do NOT teach lessons about climate change.
People who are important to my teaching expect me to teach about climate change.

TABLE 5 Items used for measuring the PSTs attitudes towards teaching about climate change, translated from German.

"I feel that the future implementation of lessons on climate change is."
Exhausting / not exhausting
Difficult / not difficult
Not important / important
Superfluous / necessary
Unusual / used to
Interesting / boring
Stressful / effortless

3.4 Path analysis

To answer our research questions, we chose a path analysis approach to investigate the relationships between the proposed variables and PSTs' intention and willingness to teach about climate

TABLE 6 Exemplary item of the used climate change concept inventory (Schubatzky et al., 2023; Schubatzky et al., 2024b).

Which statement best describes the greenhouse effect on Earth?	
A	**Solar radiation passes through the atmosphere and warms the ground. Thermal radiation emitted by the Earth is absorbed by the greenhouse gases in our atmosphere. The thermal radiation is then transmitted back towards the Earth, as well as in other directions. This causes the Earth to warm up even more.**
B	Solar radiation passes through the atmosphere and warms the ground. The ground reflects this solar radiation. This radiation is reflected back to Earth by the greenhouse gases in our atmosphere. This causes the Earth to warm up even more.
C	Greenhouse gases damage the ozone layer in our atmosphere. In doing so, they create and enlarge the hole in the ozone layer. The ozone hole allows more solar radiation to reach the Earth's surface. This causes the Earth to warm up even more.
D	Greenhouse gases in our atmosphere concentrate the incoming sunlight. The concentrated sunlight causes the Earth to warm up even more.
E	Greenhouse gases provide good insulation due to their dense concentrations. Greenhouse gases rise to the furthest extent of the atmosphere, reducing the heat exchange between the Earth and space. This causes the Earth to warm up even more.

The adequate answer is marked in bold.

change in science classrooms. This confirmatory path analysis approach allows us to check the extent to which our data is consistent with the proposed model. The model at test is an extended TPB model, where we introduced conceptual understanding of climate change and teaching experience about climate change. We applied multigroup path analysis approach to investigate the relationships between the proposed variables and their difference between pre- and posttest to answer research question two (RQ2).

4 Results

4.1 Descriptive statistics and changes when working through the tutorials

All constructs were analyzed using Rating Scale models (for the TPB constructs) or a Rasch model (for conceptual understanding), resulting in person ability estimates expressed in logits. These values are on an interval scale centered around 0, with positive values indicating above-average levels and negative values indicating below-average levels within the sample. For all constructs, person parameters are reported in logits and centered around 0, such that values above 0 indicate a generally positive level (e.g., high intention or willingness) and values below 0 indicate more negative levels. As a first step, the variables used in this study were analyzed regarding their mean score and their standard deviation, as shown in Table 7. Furthermore, we conducted t-tests to check for pre-post changes. Results thereby show that, except for PSTs' attitudes, all variables were higher in the post-test compared to the pre-test.

4.2 Correlation analysis

The results show that all variables except the PSTs' attitudes towards teaching climate change developed positively when comparing pre- and post-tests. Table 8 shows the correlations between the investigated variables for the pre-test, Table 9 shows the correlations for the post-test. In the pre-test, the intention was not significantly correlated to the PSTs self-efficacy and conceptual understanding. Furthermore, the PSTs subjective norms were not correlated with their conceptual understanding. In the post-test, subjective norms were not correlated with attitudes and conceptual understanding. All correlations except for the correlation between intention and willingness were in the range between 0.25 and 0.58, indicating no multicollinearity. Only intention and willingness were highly correlated (0.83 in the pre-test and 0.79 in the post-test), however, those two are only outcome variables in the path analyses, so the high correlation is rather unproblematic.

4.3 Multigroup-path analysis

To answer our research questions, we performed a multigroup path analysis according to the TPB, extended by the PSTs' conceptual understanding and teaching experience about climate change. To analyze which paths within the model changed from pre- to post-test (i.e., before and after working through the tutorials), we varied every single path between pre- and post-test and performed chi-square-tests to determine whether they significantly differed. Following this, we found that the paths involving and the direct path from perceived behavioral control (self-efficacy) to intention, and the direct path from conceptual understanding to willingness varied over time since this model showed the best model fit ($p < 0.01$). The final model (Figure 2) showed a good model fit (RMSEA = 0.06; SRMR = 0.07, CFI = 0.984, TLI = 0.968). Table 10 shows a summary of the model.

The analysis showed that in the pre- as well as the post-test, the PSTs' subjective norms ($\beta = 0.47$, $p < 0.01$), attitudes ($\beta = 0.72$, $p < 0.01$) and perceived behavioral control ($\beta = 0.50$, $p < 0.01$) directly predicted their willingness to teach about climate change explaining 38% variance in the pre-test and 35% in the post-test. Furthermore, the PSTs' subjective norms ($\beta = 0.81$, $p < 0.01$) and attitudes ($\beta = 1.57$, $p < 0.01$) directly predicted their intention to teach about climate change. However, the PSTs perceived behavioral control (self-efficacy) only predicted the intention in the post-test ($\beta = 0.56$, $p < 0.01$), but not in the pre-test ($p = 0.72$). In the pre-test, 35% of intention variance was explained, and 30% in the post-test.

The results additionally show that the PSTs' conceptual understanding of climate change predicted their attitudes toward teaching about climate change ($\beta = 0.15$, $p < 0.01$) as well as their perceived behavioral control ($\beta = 0.46$, $p < 0.01$). Teaching experience also predicted perceived behavioral control ($\beta = 0.35$, $p < 0.01$). In total, 5% variance in the PSTs' attitudes was explained in the pre-test, and 15% in the post-test. 15% of variance in perceived behavioral control was explained in the pre-test and 35% in the post-test. Lastly,

TABLE 7 Descriptive statistics of all variables including *t*-test statistics to investigate pre-post changes in these variables.

Variables	Pre-test measure in logits		Post-test measure in logits		*t* statistic	*p* value	Effect size
	M	SD	*M*	SD	t(70)	*p*	*d*
Intention	2.35	1.75	2.81	1.64	2.54	<0.05	0.30
Willingness	2.19	1.36	2.68	1.37	2.95	<0.01	0.35
Self-Efficacy	1.19	0.84	1.96	0.73	6.33	<0.001	0.75
Social Norms	1.33	1.00	1.66	0.89	2.31	<0.05	0.27
Attitudes	1.10	0.46	1.06	0.38	0.53	0.60	
Conceptual Understanding	0.92	0.65	2.05	0.96	11.16	<0.001	1.32

the PSTs' conceptual understanding did not predict their willingness to teach about climate change in the pre-test ($p = 0.76$).

5 Discussion

First, our results show that during the intervention, the PSTs developed their conceptual understanding, their self-efficacy as well as intention and willingness to teach about climate change. Thereby, we make the claim that working through our materials, *Tutorials in Climate Change*, helped to positively develop the afore mentioned aspects.

Furthermore, we have shown that TPB is applicable for explaining PSTs' intention and willingness to teach about climate change. Demonstrating the applicability of TPB in this context is relevant because it provides a framework to investigate different factors that shape teachers' teaching behavior. Such a framework can inform the design of teacher education by identifying which belief as well as knowledge domains need to be addressed to increase teachers' intention and willingness to teaching climate change. It also allows future research to evaluate the effectiveness of interventions by examining their impact on these specific determinants. The following sections discuss how the constructs of the TPB related to PSTs' conceptual understanding and how their relationships differed between pre- and posttest.

5.1 RQ1: What is the role of conceptual understanding of CC for the intention to teach about CC?

Our results regarding Research Question 1 (RQ1) indicate PSTs' conceptual understanding of climate change plays a significant role in shaping their intention and willingness to teach about this topic. Specifically, the findings reveal that conceptual understanding directly predicts self-efficacy ($\beta = 0.46$) and attitudes ($\beta = 0.15$) towards teaching climate change, which in turn influence their teaching intention and willingness.

The strong relationship between conceptual understanding and self-efficacy supports the notion that teachers who possess a solid grasp of climate science feel more confident in their ability to teach the subject. This aligns with previous research (e.g., Lambert et al., 2012; Liu et al., 2015), which suggests that increasing teachers' content knowledge enhances their teaching self-efficacy. In our study, PSTs with a higher level of understanding about the scientific principles of climate change felt more prepared and less overwhelmed by the prospect of teaching it. This sense of preparedness likely stems from a deeper comprehension of the content, which equips teachers with the tools necessary to address students' questions and misconceptions effectively.

In addition to conceptual understanding, teaching experience was also a significant predictor of self-efficacy. PSTs with prior teaching experience concerning the topic of climate change reported higher confidence in their ability to teach about climate change. This suggests that beyond content knowledge, practical classroom experience may play an important role in shaping PSTs' self-efficacy, which aligns with the TPB assumption that self-efficacy is partly informed by mastery experiences (Bandura, 1977). Teacher education programs might therefore benefit from combining teaching opportunities with targeted content instruction to build both knowledge and confidence.

Our findings also indicate a positive relationship between conceptual understanding and attitudes towards teaching climate change. Teachers with a sound understanding of climate change generally have more positive attitudes towards teaching it. This may be because they perceive the task as less challenging and more manageable, knowing they have a strong foundation of knowledge to rely on. Additionally, a thorough understanding of the subject may increase teachers' appreciation of its importance, thus fostering more positive attitudes towards teaching it. This is consistent with the Theory of Planned Behavior, which posits that attitudes towards a behavior significantly influence intention (Ajzen, 1991).

Interestingly, our results show that conceptual understanding does not significantly predict subjective norms. This suggests that while teachers' knowledge impacts their confidence and attitudes, it does not necessarily alter the perceived social pressures or expectations from significant others regarding teaching climate change. Subjective norms are more likely influenced by external factors such as institutional policies, peer influence, and societal expectations, rather than individual content knowledge. Future research could explore additional factors that influence subjective norms to provide a more comprehensive understanding of this aspect.

These findings have important implications for teacher education programs. To enhance PSTs' intention and willingness to teach about climate change, programs should prioritize improving conceptual understanding through targeted interventions and comprehensive training. By doing so, they can foster self-efficacy and more positive attitudes among PSTs, ultimately encouraging them to incorporate climate change education into their teaching practices.

TABLE 8 Correlations between investigated variables for the pre-test (N = 71), an asterisk marks a significant correlation ($p < 0.05$).

	Willingness	Self-efficacy	Subjective norms	Attitudes	Conceptual understanding
Intention	0.83*	0.19	0.50*	0.52*	0.14
Willingness	1	0.45*	0.43*	0.47*	0.25*
Self-Efficacy		1	0.28*	0.36*	0.39*
Subjective norms			1	0.40*	−0.03
Attitudes				1	0.22*

TABLE 9 Correlations between investigated variables for the post-test (N = 71), an asterisk marks a significant correlation ($p < 0.05$).

	Willingness	Self-efficacy	Subjective norms	Attitudes	Conceptual understanding
Intention	0.79*	0.51*	0.41*	0.38*	0.24*
Willingness	1	0.58*	0.50*	0.44*	0.39*
Self-efficacy		1	0.30*	0.57*	0.58*
Subjective norms			1	0.07	0.19
Attitudes				1	0.39*

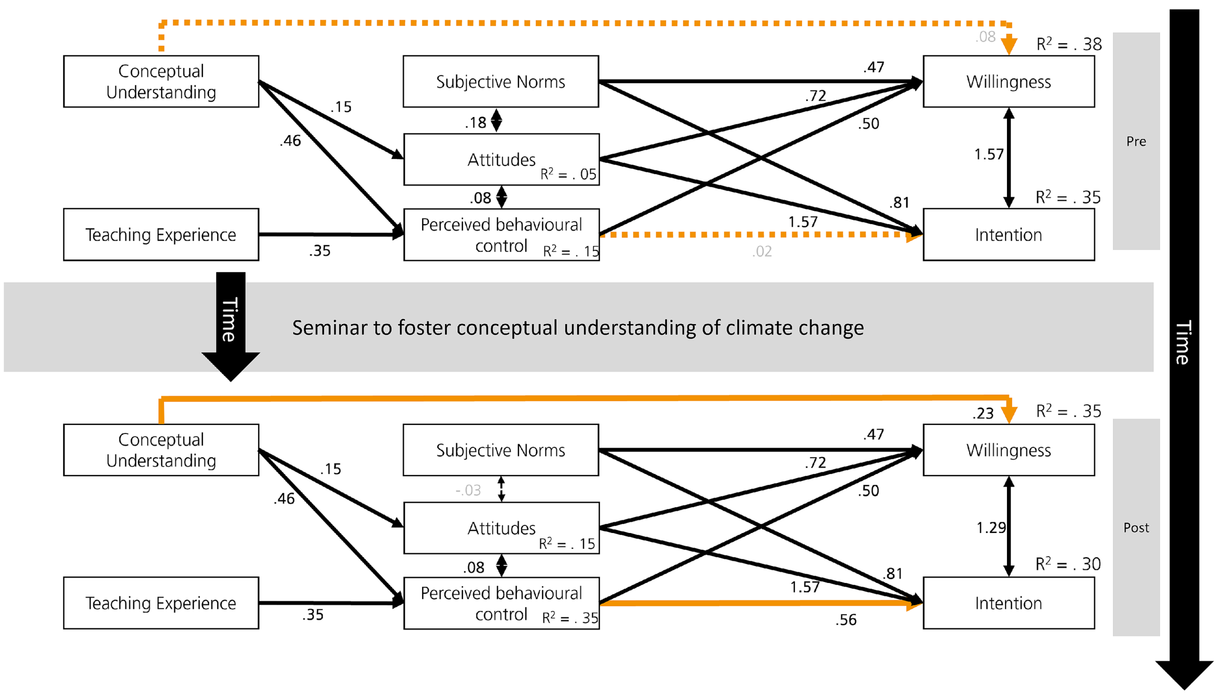

FIGURE 2
Multigroup path model analyzed in this study based upon the TPB. Bold paths indicate significant paths, dashed paths indicate non-significant paths.

5.2 RQ2: How do physics pre-service teachers' intention and willingness to teach about climate change differ between a low-knowledge and a high-knowledge state resulting from working through tutorials in climate change?

RQ2 explored how the role of conceptual understanding of climate change in influencing the intention and willingness to teach about the topic differs between a low-knowledge (pre) and a higher-knowledge (post) state created by working through the tutorials in climate change (Wildbichler et al., 2025b).

Working through the tutorials in climate change significantly improved PSTs' conceptual understanding, as evidenced by the substantial pre-post-test differences ($d = 1.32$). This increase in knowledge was accompanied by gains in self-efficacy ($d = 0.75$), willingness ($d = 0.35$) and intention ($d = 0.30$) to teach about climate change, while attitudes remained stable at an already high level.

TABLE 10 Summary of the multigroup-path model comparing pre-test and post-test.

Path	Pre-test (Beta)	Standard error	*z*-value	*p*-value	Post-test (Beta)	Standard error	*t*-value	*p*-value
Subjective Norms → Willingness	0.47	0.11	4.49	<0.001*				
Subjective Norms → Intention	0.81	0.16	5.11	<0.001*				
Attitudes → Willingness	0.72	0.25	2.86	<0.01*				
Attitudes→ Intention	1.57	0.38	4.11	<0.001*				
Perceived Behavioral Control (Self Efficacy) → Willingness	0.50	0.14	3.48	<0.001*				
Perceived Behavioral Control (Self Efficacy → Intention)	−0.02	0.24	−0.09	0.93	0.56	0.27	2.06	<0.05*
Conceptual Understanding → Willingness	0.08	0.13	0.61	0.54	0.23	0.11	2.10	<0.05*
Conceptual Understanding → Attitudes	0.15	0.04	4.12	<0.001*				
Conceptual Understanding → Perceived Behavioral Control (Self Efficacy)	0.46	0.06	7.24	<0.001*				
Teaching Experience → Perceived Behavioral Control (Self Efficacy)	0.35	0.14	2.47	<0.05*				

An asterisk marks a significant path. For the post-test, only changing paths were reported.

These findings indicate that targeted instruction on the scientific underpinnings of climate change can effectively enhance both conceptual understanding and motivational determinants. This aligns with previous research suggesting that building content knowledge strengthens teachers' self-efficacy and preparedness (Lambert et al., 2012; Liu et al., 2015).

Comparing the TPB model between the low-knowledge and high-knowledge states reveals that conceptual understanding played a more central role after the intervention. Post-intervention, its relationship with self-efficacy strengthened, explaining a larger proportion of variance and indicating that deeper conceptual understanding fostered PSTs' confidence in their ability to teach the topic. Similarly, conceptual understanding explained a greater proportion of variance in PSTs' attitudes towards teaching climate change after working through the tutorials. This suggests that as PSTs became more knowledgeable, they also perceived the topic as more important and less difficult to teach, fostering more positive attitudes. Notably, conceptual understanding directly predicted PSTs' willingness to teach about climate change in the post-test, a relationship not present in the pre-test model. This suggests that increased understanding may not only enhance confidence but also lead to a stronger intrinsic motivation to engage with the topic. In contrast, intention appears to be shaped more strongly by external expectations, as indicated by the finding that subjective norms predicted intention more strongly than willingness before the intervention. This aligns with the conceptual distinction between the two constructs: intention represents a conscious plan to act that is often influenced by perceived social pressure, whereas willingness reflects an affective readiness to act under voluntary conditions (Gerrard et al., 2008; Fasching et al., 2025; Heuckmann et al., 2020). After working through the tutorials in climate change, as PSTs' conceptual understanding grew, willingness became directly predicted by knowledge, suggesting that enhanced understanding can foster more internalized motivation, while subjective norms continued to influence intention. The role of subjective norms remained consistent between pre- and post-intervention, continuing to predict both intention and willingness to teach about climate change. This stability suggests that social pressures and expectations perceived by PSTs may be more resistant to change. These norms are likely influenced by broader institutional and societal factors that extend beyond the scope of working through tutorials.

The findings from RQ2 highlight the value of professional development programs in climate change education. While initial improvements in conceptual understanding are crucial, ongoing support and education could further strengthen the positive impacts on self-efficacy, attitudes, and willingness to teach. Teacher education programs should consider integrating continuous, comprehensive climate change modules that do not only focus on the scientific underpinnings of climate change throughout their curricula to maintain and build upon initial gains in PSTs' knowledge and confidence.

6 Limitations

This study, while providing valuable insights into PSTs understanding and intention regarding climate change education, has several limitations that should be considered when interpreting the results.

One potential limitation of this study is that the participating PSTs already showed relatively high levels of intention and willingness to teach about climate change at the pre-test, with mean person estimates above 0. This indicates that there was little initial hesitancy in the sample. This strengthens the relevance of our intervention for motivated future teachers, but it also means that the observed increases occurred from an already relatively high baseline.

The sample size of 71 PSTs, while sufficient for the analyses conducted, is comparably small. A larger sample size would provide more robust data and increase the validity of the findings. Future studies should try to generalize these findings. However, the strength of this sample lies in its diversity, encompassing participants from three different countries and five universities.

The implementation of climate change tutorials varied across the universities involved in the study. While this variability can be seen as a limitation, as it introduces potential inconsistencies in the intervention, it can also be considered a strength. The varied implementation demonstrates that the positive outcomes observed are robust across different instructional contexts and teaching contexts. Furthermore, our study did not include a control group, which limits the ability to definitively attribute the observed changes in PSTs' understanding and intention to the intervention. Future studies should include a control group to better isolate the effects of a conceptual understanding-based intervention.

The survey items used to measure variables such as intention and willingness to teach about climate change were relatively general. They did not specify whether the questions referred to teaching specific content knowledge or the assessment of climate adaptation and mitigation measures. More specific items could provide deeper insights into the different aspects of climate change education.

Some of the measures used in the study exhibited rather low reliability scores. While most variables showed acceptable reliability, the lower reliability of certain measures suggests that future research should refine these instruments to ensure more consistent and reliable data collection.

Additionally, while the TPB provided a valuable framework for investigating the cognitive and affective determinants of pre-service teachers' intention and willingness to teach about climate change, it is important to acknowledge its limitations. TPB primarily focuses on individual-level beliefs, attitudes, and perceptions, and may therefore insufficiently account for broader contextual or structural influences. Factors such as curriculum mandates, institutional support, school culture, or socio-political pressures—although highly relevant for climate change education—are not explicitly modeled within the TPB framework. As a result, the explanatory power of the model may be limited when it comes to understanding how systemic conditions facilitate or hinder teachers' implementation of climate-related instruction (Liou et al., 2019). Future research could address this limitation by integrating complementary theoretical perspectives, such as models of teacher agency, to capture the full complexity of decision-making in educational contexts.

Furthermore, the *Tutorials in Climate Change* directly addressed the most common difficulties established by the CCCI-422 (Schubatzky et al., 2024a; Schubatzky et al., 2024b). Therefore, one limitation of our study is that our intervention was closely related to the test, as the materials directly addressed the most difficult questions in the test. In addition, the CCCI-422 was developed from a science education perspective and hence focuses on the physical science of climate change, as opposed to a broader conceptual understanding of climate change, e.g., including adaptation and mitigation measures.

Despite these limitations, the study contributes valuable insights into the role of conceptual understanding in PSTs' intention and willingness to teach about climate change. The findings underscore the importance of enhancing PSTs' knowledge of climate science to improve their self-efficacy and attitudes towards teaching this critical subject. Future research should address the mentioned limitations to further validate and expand upon these findings.

7 Conclusion

Our study sheds light on the significant role of physics PSTs' conceptual understanding of climate change in shaping their intention and willingness to teach about this important topic. Using an extended TPB model, our findings highlight that enhancing physics PSTs' understanding of the scientific principles underlying climate change positively impacts their self-efficacy and attitudes towards teaching climate change, which in turn boosts their intention and willingness to integrate climate change education into their future classrooms.

Our research demonstrates that while subjective norms and attitudes are consistent predictors of intention and willingness to teach about climate change, the influence of perceived behavioral control (self-efficacy) becomes particularly important following a targeted educational intervention. This underscores the importance of incorporating climate science education into teacher preparation programs to build PSTs' confidence and knowledge in teaching climate change.

The study also reveals that the relationships within the TPB model differ between pre- and posttest, suggesting that continued exposure to and engagement with climate change education materials further solidifies physics PSTs' intention and willingness to teach about climate change.

Despite the limitations related to sample size, variability in tutorial implementation, and the absence of a control group, this study provides valuable insights into the factors influencing physics PSTs' readiness to teach climate change. The diverse sample across multiple countries and universities adds a level of cross-country relevance, suggesting that the findings may have broader applicability.

Future research should address the limitations identified, including incorporating a control group and including Pedagogical Content Knowledge to gain a more holistic understanding of the factors driving PSTs' intention and willingness to teach about climate change. Additionally, exploring the long-term impacts of these educational interventions on in-service teachers would further advance our understanding.

In conclusion, enhancing physics PSTs' conceptual understanding of climate change is crucial for supporting confident and capable teachers who can effectively teach about climate change. Teacher education programs must prioritize climate science education and provide ongoing support to make sure that future generations are well-equipped to address the challenges of a changing climate.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical approval was not required for the studies involving humans. The studies were conducted in accordance with the local legislation and institutional requirements. Participation was based on informed consent. The PSTs were informed about the purpose of the study, the data processing, and that participation was voluntary. Consent was obtained in written form. The PSTs were informed that their participation was voluntary, and that nonparticipation did not have any negative consequences. All data collected during the research were treated with utmost confidentiality and privacy. Identifying information about participants was carefully safeguarded, and data reporting in the manuscript maintains anonymity.

Author contributions

TS: Investigation, Project administration, Formal analysis, Writing – original draft, Writing – review & editing, Data curation, Methodology, Conceptualization, Visualization, Funding acquisition. SW: Writing – review & editing, Data curation, Investigation, Conceptualization, Validation, Project administration, Writing – original draft. RW: Writing – original draft, Writing – review & editing, Funding acquisition, Project administration, Conceptualization. MD: Project administration, Conceptualization, Writing – review & editing, Writing – original draft, Funding acquisition. LI: Conceptualization, Funding acquisition, Project administration, Writing – review & editing, Writing – original draft. MM: Writing – original draft, Funding acquisition, Data curation, Writing – review & editing, Conceptualization. GP: Writing – review & editing, Project administration, Conceptualization, Funding acquisition, Writing – original draft.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The authors declare that Gen AI was used in the creation of this manuscript. Generative AI was used for language refinement and editing suggestions during the preparation of this manuscript. All content, including the interpretation of results and the structure of the argument, was generated by the authors and critically reviewed by them. The authors take full responsibility for the final version of the manuscript.

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