Teaching Climate Change through Inquiry-Based Learning to Pre-Service Geography Teachers
A Case Study

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Abstract:

Education is key to addressing the climate crisis and Inquiry-Based Learning is a promising approach. Therefore, qualitative changes in selected constructs related to the teaching and learning of pre-service geography teachers at the University of Augsburg who participated in a seminar intervention with this focus were investigated. This explorative case study uses interviews, a group discussion, and written reflections. Main findings include an increased attribution to importance of IBL, the added value of characteristic implementation principles as well as an enhancement in students' epistemological beliefs and dispositions to act.

Keywords: *Inquiry-Based Learning, Climate Change Education, Dispositions to Act, Teacher Education*

Bildung ist ein Schlüsselfaktor zur Bewältigung der Klimakrise und forschendes Lernen ist ein vielversprechender Ansatz. Daher wurden qualitative Veränderungen ausgewählter Konstrukte des Lehrens und Lernens von angehenden Geographielehrkräften an der Universität Augsburg untersucht, die an einer Seminarintervention mit diesem Schwerpunkt teilnahmen. Diese explorative Fallstudie basiert auf Interviews, einer Gruppendiskussion und schriftlichen Reflexionen. Zu den Hauptergebnissen gehören eine erhöhte Bedeutungszuschreibung von IBL, der Mehrwert charakteristischer Umsetzungsprinzipien, sowie eine Heraufsetzung epistemologischer Überzeugungen und Handlungsdispositionen.

Stichwörter: *Forschendes Lernen, Klimawandelbildung, Handlungsdispositionen, Lehrerbildung*

1. Introduction

In the Anthropocene, a human-dominated era, the world is increasingly characterised by volatility, uncertainty, complexity and ambiguity (Crutzen, 2002; Mack & Khare, 2016). This is accompanied by multiple challenges, such as the overshooting of planetary boundaries. This threatens the ability of various earth systems to regenerate and, in turn, increasingly limiting the safe space for human activity on the planet (Richardson et al., 2023; Steffen, Richardson, et al., 2015). Thus, the need for education that equips young people, our future decision-makers, to navigate these characteristics of the 21st century is growing (Bohunovsky & Keller, 2023; Waller et al., 2019).

In current conversations about the trajectories of future education, the importance of adequate teacher training is emerging as a central focus (Darling-Hammond, 2023; Li et al., 2019; Olsen et al., 2020). First, teachers have a profound impact on the education of students, and second, there is a multiplier effect of educators on society, which extends through generations of students within teachers' careers (Hattie, 2023; Heafner, 2016). High-quality teacher training is therefore a legitimate and reasonable claim.

Likewise, there is general agreement about central topics within geography education that tackle the aforementioned 21st century challenges, with climate change being one of the most prominent (Leal Filho & Hemstock, 2019). This crisis is widely discussed in society and calls for education that cultivates climate literacy (Alkaher, 2020; Azevedo & Marques, 2017). A particularly promising strategy to teach climate change is Inquiry-Based Learning (IBL) (Brumann & Ohl, 2019; Keller et al., 2019). The literature shows that it has the potential to address some of the most common challenges in Climate Change Education (CCE) (Bush et al., 2017; Namdar, 2018). These comprise, for example, a high complexity (both normative and factual) of the topic, persistent alternative conceptions and a perceived psychological distance (Brumann et al., 2022). Paradoxically, while the benefits of this approach are widely recognised, its implementation remains limited in schools (Brumann et al., 2022; Brumann et al., 2019). This is compounded by the circumstances that future teachers often have little scientific training and limited familiarity with the core principles of IBL (Competente, 2019). However, a study by Chichekian and Shore (2016) demonstrated that educators who had prior exposure to inquiry-based experiences during their education or had engaged in genuine research were more inclined to implement the approach.

The main goal of this exploratory study is to record the experiences of students participating in a seminar intervention and to evaluate the implications. To assess the potential of IBL in the context of CCE, three sets of data from a seminar with pre-service geography teachers specialising in secondary geography education were analysed: a group discussion, interviews and written student reflections on the seminar.

This paper first addresses theoretical considerations and the state of the research, followed by the aim and research questions of the study. A brief description of the seminar concept, the methodology of the study and the results are then presented. Finally, limitations, positionality, and results are discussed.

2. Theoretical Background and State of Research

The current era of Great Acceleration, in

which humans are increasingly influencing natural systems and the scope for action is dwindling, highlights the need for a democratically initiated socio-ecological transformation (Seitz, 2015; Steffen et al., 2015). The anticipated safe and just corridor for human action can be interpreted as a broad normative framework for educational practices in which social foundations are to be protected and planetary boundaries that must not be exceeded (Dearing et al., 2014; Raworth, 2020).

Education occupies a key position when preparing societies for the challenges and changes of the 21st century (Deisenrieder et al., 2020). In 2011, the WBGU (German Advisory Council on Global Change) called for education to make a decisive contribution to transformation, and furthermore, Kopatz (2019) states that education is the breeding ground for a successful transformation. Nevertheless, the conventional education system (in German-speaking countries), which is anchored in capitalist and economic-liberal structures, reproduces inequality and remains comparatively unchanged in content, goals, concepts, and basic systematic structures (Benz, 2014; Bohunovsky & Keller, 2023; Keller, 2020). Approaches that are currently discussed as contributors to change within educational systems will therefore be briefly presented in the following section.

2.1 Climate Change Education (CCE)

Climate change is a multifaceted sub-crisis of the multiple crises and will be addressed as such here (Brand & Wissen, 2017). Geography, with its integrative lens, is the central subject for CCE in Germany as it focuses on the natural and social interdependencies of the topic (Hoffmann, 2023).

CCE as an overarching approach, with distinctive goals, can help to plan and implement adaptations with respect to current and future impacts of climate change through educational measures (Fernandez at al., 2014). More specifically, CCE aims to raise awareness of the causes, consequences and management of climate change, which is why learning takes place in the face of risk, ambiguity, uncertainty and rapid change (Rousell & Cutter-Mackenzie-Knowles, 2020; Stevenson et al., 2017). Enhancing critical and creative thinking, a basic understanding of climate science, skills in accessing, using, and communicating information, and a positive attitude towards contributing to solutions play a central role in this approach, if the goal is to enhance climate literacy (Azevedo & Marques, 2017; Nepraš et al., 2022).

Anderson (2012) states in this context that educational interventions are most successful when they focus on local, tangible, and actionable aspects of climate change, which is why the learning environment – namely schools – should be targeted and made climate resilient (for more detailed discussion of effective CCE strategies, see Monroe et al., 2019). Since educators have a profound impact on the learning processes of students (Blazar & Kraft, 2017; Hattie, 2023; Titsworth et al., 2015), it makes sense that geography educators play a central role in shaping young people into citizens capable of understanding and making informed decisions about the global climate crisis (Hestness et al., 2014).

So far, though, participatory, interdisciplinary, creative and affect-driven approaches to CCE are rare (Rousell & Cutter-Mackenzie-Knowles, 2020). Also, the important area of climate action, where learners develop specific knowledge, skills and attitudes to deal with climate change on a systematic and individual level, has

not yet been addressed sufficiently (Anderson, 2012; Bohunovsky & Keller, 2023; Kranz et al., 2022; Stevenson et al., 2017). A possible explanation for that might be the factual and ethical complexity of the topic, which leads to possible pitfalls like the responsabilisation or indoctrination of individual students, which is rejected in an educational setting (Hanke et al., 2023; Meyer et al., 2018; Ohl, 2013). Also, there is still a broader discussion about finding definitions of what appropriate climate action is and what goals shall be achieved specifically by education (Franco et al., 2020).

This area of climate action has predominantly been under investigation in the research field of psychology (Bliesner-Steckmann, 2017). Here, different models of action can be devised to identify dispositions to climate action, which range from emotions over knowledge all the way to societal factors (for more detailed information on this see Hamann et al., 2016; Kollmuss & Agyeman, 2002; Montaño & Kasprzyk, 2008; Rost et al., 2001). Other challenges for CCE include the psychological distance from climate change, uncertainty, disinformation, common misconceptions and a lack of understanding of scientific knowledge production around the issue (Chiari et al., 2016; Hanke et al., 2022; Höttecke & Allchin, 2020; Renn, 2018).

Altogether, CCE encompasses a range of approaches that share common goals of raising awareness, climate literacy and action around the climate crisis. However, they are not easily achieved due to the inherent challenges of the topic (Chang, 2023; Neuer & Nöthen, 2023).

2.2 Inquiry-Based Learning (IBL)

A promising approach to deal with the aforementioned challenges is IBL (Bush et al., 2017). IBL "refers to educational workforms, which serve the search for[, presenting] and finding of knowledge that is new (at least) to the learner, and which happen analogous to the characteristics of scientific knowledge production regarding attitude, methods, and systematic proceeding" (Brumann et al., 2022, p. 3). Its origins lie in a social-constructivist approach that is student-centred and has similarities with experiential and project-based formats (Chu et al., 2017; Tan & Seow, 2022).

A central goal of this approach is the development of a mindset characteristic of a researcher and of scientific literacy (see Wessels et al. 2019).

As an experiential and project-based format, IBL shows several potentials with regard to CCE: Keller et al. (2019) for example found that the impact of CCE in educational settings is higher when students conduct their own research. The IBL approach helps students to personally experience the causes and impacts of climate change, via research-related processes, in their immediate surroundings (Brumann & Ohl, 2019). Overall, it represents an innovative teaching strategy that promotes learner-centred knowledge construction and thus the potential for greater understanding and integration of content (Lower-Hoppe et al., 2021).

There is a spectrum of close-to-science IBL formats to more toned down and highly didact formats, which leads to a variation of epistemic activity, duration, self-directedness, content, methodological repertoire, science orientation, and quality of findings (Brumann & Ohl, 2019). Pedaste et al. (2015) present a synthesized framework that suggests that concrete implementations should be oriented towards an authentic research cycle (more on design principles to conceptualize con-

crete IBL approaches to climate change see Brumann et al., 2022).

2.3 Role of the teacher in implementing IBL in CCE

Teachers play a central role in successfully implementing IBL (Rehorek, 2004). Nevertheless, teachers often do not feel adequately prepared to implement this approach, as they lack adequate training in this regard (Boon, 2016). They also express concerns about their students' competencies and their own working context when it comes to implementing IBL (Zur & Tal, 2021). Furthermore, the approach demands a shift of the teacher role from being a "sage on the stage" to a "guide on the side" (King, 1993, p. 30) – a guide who is also a co-learner and facilitator of inquiry (Furtak et al. 2012). Additionally, Competente (2019) states that pre-service teachers have limited foundational knowledge about climate science and consequently lack the necessary prerequisites to teach climate change through IBL.

These are indicators why IBL approaches are not yet widely realised in school contexts, which suggests a need for institutionalised efforts to teach the concept in pre-service teacher education, especially in a climate change context (Brumann et al., 2022). This implementation gap is particularly pressing when considering that genuine inquiry is conceptualised as a transformative force for teacher development, student learning, and school change (Schulz, 2010).

3. Research Questions

The aim of the study is to record the experiences of students participating in the seminar *Inquiry-Based Learning on Geographical Topics in the Context of Climate Change*. More specifically, the study will assess the subjective importance of the approach as experienced by the pre-service teachers, as well as the various opportunities and challenges of the concept from their perspectives. The overarching research question (RQ) along with its subquestions are therefore:

RQ: What experiences can pre-service geography teachers gain through participation in an IBL seminar on climate change?

SQ1: What significance do pre-service geography teachers attribute to IBL in the context of climate change?

SQ2: What experiences can pre-service geography teachers gain in a seminar through the IBL approach in the context of climate change that support them in implementing the approach at school?

SQ3: To what extent can a seminar, using the IBL approach on climate change, contribute to differentiated perceptions of climate science?

SQ4: To what extent can a seminar using the IBL approach to climate change, strengthen pre-service geography teachers' dispositions to act on climate change?

4. Research Methodology

The research was carried out at the University of Augsburg in Bavaria, Germany, between September 2022 and October 2023. The research design involved a seminar design, multiple data collection strategies and the triangulation of findings to ensure a comprehensive understanding of the phenomenon under investigation and the quality of the findings (Carter et al., 2014). The research process consisted of several sequential steps, including the imple-

mentation of the seminar, group discussions, individual episodic semi-structured interviews, and the evaluation of student submissions. This exploratory qualitative case study was designed to capture the perspectives, experiences and challenges of future teachers in depth and to allow for emergent findings that could not be derived from the current literature.

4.1 The Seminar Concept

A key finding of Leal Filho et al. (2021) suggests that specific strengths and weaknesses should be considered in a curriculum when implementing CCE and such an examination by the author revealed a lack of basic scientific literacy among students which this study aims to fill. For this reason, a seminar concept has been developed which takes into account the professional competence of teachers (c.f. Kunter et al., 2011 for further details). The seminar *Inquiry-Based Learning on Geographical Topics in the Context of Climate Change* is part of the didactic training within the teacher training programme for geography teachers in secondary schools in Bavaria (*Realschule and Gymnasium*). The seminar is aimed at students in higher semesters pursuing a State Exam, which presupposes a completed basic education in geography and geography didactics. In total, eleven students participated in the seminar on a voluntary basis, all of whom had German or English as a second subject of study. The students had previously studied at the University of Augsburg for between 4 and 15 semesters. The seminar was carried out together with a second lecturer from the chair of geography education in one semester, between October 2022 and February 2023, with a total of 14 sessions. In these sessions, students were part of an authentic research cycle and were given the opportunity to reflect on didactic implications for secondary educational settings.

The seminar concept was based on the theory briefly outlined above and an existing concept for upper secondary schools (Brumann et al., 2019), which was adapted for teacher training. It aims to address the importance of IBL in the context of climate change, offer practical experiences that support the application of IBL in schools, promote differentiated perceptions of climate science, and indirectly foster dispositions toward climate action through meta-reflection. The dramaturgy of the seminar consists of eight modules:

(1) In the first two sessions, students were introduced to the basics of research in general and the IBL approach in particular, taking into account previous study experience. (2) Students then worked through interactive learning modules that explored the causes, consequences and impacts of climate change at global and local levels. Afterwards, they worked on and presented interest-driven learning modules on different topics such as the knowledge-action gap, climate change and the city, climate change and soil and many more. (3) This was followed by an introduction to geographical research methods in the form of a gallery walk. Using brainstorming and topic refinement methods, the students developed interest-driven topic areas for their own research and revised them using peer review procedures. The topics were then further narrowed down and research questions were formulated, evaluated, revised and presented. Students developed a research methodology design and resubmitted it for peer feedback. (4) Subsequently, in a separate session, they reflected on the research progress so far from the pupils' point of view, taking into account the didactic im-

plications of such an approach and their experiences so far. (5) Thereafter, several weeks of fieldwork and data collection were conducted (depending on the research design, they conducted interviews, took samples or measurements), with students coming to the university for regular sessions of reflection on research progress and peer feedback evaluation. (6) Two sessions of data analysis and interpretation gave students the opportunity to present their progress and ask questions. (7) The final session was another didactic reflection session in which students participated in a group discussion guided by key questions. (8) Finally, the students wrote their research reports and didactic reflections and submitted them to the lecturers.

4.2 Data Collection

Initially, group discussion prompts and interview questions were developed deductively based on the research objectives and literature in the field. To ensure the validity, quality, and relevance of the prompts, a consensual evaluation was conducted in collaboration with the second instructor, an expert in the field of CCE through IBL. Feedback and refinements were incorporated to improve the clarity and effectiveness of the discussion and interview tools. The template for student submissions was also developed by mutual agreement.

The first phase of data collection involved a group discussion with eleven pre-service geography teachers who had attended the seminar. The discussion lasted 87 minutes. The group discussion format was chosen to encourage open dialogue and the sharing of different perspectives on their experiences of IBL in the context of CCE, while helping them recall and articulate experiences they might overlook in a one-on-one setting (Bortz & Döring, 2006; Nind, 2019). The discussion was facilitated by the researcher and the second lecturer.

Following the group discussion, six individual semi-structured episodic interviews were conducted with pre-service geography teachers (lasting between 30 and 50 minutes). This sequence was chosen to avoid recall bias, while also helping students to better structure and articulate their thoughts. Students were asked to share their individual reflections with a focus on lived experiences to avoid a conformity bias. The episodic interviews provided an opportunity to explore the participants' personal experiences, perceptions and reflections in relation to the seminar in depth (Flick, 2011; Mueller, 2019). It also allowed for a reduction of the social desirability bias in comparison to the group discussion. The semi-structured format allowed for flexibility in exploring specific themes, while maintaining consistency across interviews (Adams, 2015). Both the audio of the group discussion and individual interviews were recorded and transcribed verbatim.

As an additional source of data, student-written reflections were evaluated (ranging from seven to nine pages). At this stage, participants were asked to submit reflections on their seminar experience from a didactic point of view. These submissions were analysed to gain insights into how participants viewed the didactic aspects of the seminar, the effectiveness of IBL and its impact on learning. This format was chosen because it allows students to elaborate more deeply on their seminar experience. They were asked to share their concrete perspective on the seminar and only their didactic analysis of these was

part of their grade.

4.3 Data Analysis

Data from these three sets of instruments were then analysed qualitatively following the methodology proposed by Kuckartz and Rädiker (2022). This was chosen in this explorative study to ensure an inductive and flexible analysis, allowing for data-driven category development while still enabling deductive elements. The transcripts served as the primary data source for the qualitative analysis. They were imported into MAXQDA 2020 (20.4.2) for systematic coding. Initially, a deductive code system was developed in line with the pre-defined research objectives and the literature. This code system provided a structured framework for organising and analysing the data. In addition to deductive coding, an inductive approach was used to extend the code system based on emergent themes and patterns identified during the analysis (Azungah, 2018). The data were analysed two times with the second coding cycle being carried out in MAXQDA 2022 (22.7.0). This iterative process allowed for a more nuanced understanding of participants' experiences.

The same code system was then also applied to the student submissions. The coded data from both the group discussion and individual interviews were integrated to identify commonalities, variations, and overarching themes. The 377 coded segments served as the basis for the subsequent integration and interpretation of the qualitative data.

5. Results

This study sought to answer the research question “What experiences can pre-service geography teachers gain through participation in an IBL seminar on climate change?”, subdivided into four distinct research questions, each addressing a different aspect of the educational approach. The results will be presented in the respective subchapters. All quotes presented in this section are translations of the original German-language data.

5.1 RQ1: Significance of Inquiry-Based Learning in Climate Change Education

The first research question explores the importance that pre-service geography teachers attach to IBL in the context of climate change.

Climate Change Communication: Enhanced Argumentation Skills, Shift in Perspective, and Empathy

Improved perceived argumentation skills emerged as an important outcome of IBL. Many participants reported an improvement in their ability to construct well-reasoned arguments and to communicate their views effectively to others. For example, interviewee 5 said, *"I talk to friends or relatives or whatever or colleagues about the experiences from the seminar and that alone stimulates a discussion which, in the best case, leads to me convincing the others with my argumentation that it would be quite clever to do something for"* (ep. interview 5, Pos. 69).

In addition, students reported a shift in perspective. Engaging in research and experiential learning encouraged them to look at climate change through a more critical and multifaceted lens, considering its implications from different angles. The seminar experience encouraged some participants to consider the perspectives of people from different backgrounds and communities, fostering empathy and a more nuanced understanding of different viewpoints. This can be illustrated by the following excerpt: "*Often you think that*

people in your own study programme perceive it [climate change] relatively similarly, but in the end people who come from different families with different backgrounds perceive things quite differently" (ep. interview 1, Pos. 71). This experience challenged their preconceptions and broadened their awareness beyond their own academic social circle.

Interest and Knowledge: Intrinsic Motivation, Broadened Knowledge Base, and Personalized Learning

The initial introductory phase of the seminar and the reflection sessions in which participants talked about their respective projects led to a broadening of their knowledge base according to a few students. They gained a more interconnected understanding of different aspects of climate change, including its scientific basis and its social and environmental impacts. Participant 6 mentioned, *"that climate change simply has an influence on many areas. And sometimes we forget how strong it is or how many areas it has an influence on"* (ep. interview 6, Pos. 22). However, some interviewees noted that this comprehensive understanding was pivotal but that it overlapped with much of their previous academic experiences regarding the climate crisis. More importantly, the seminar experience deepened participants' interest in the climate crisis, leading to increased curiosity and engagement with the topic, especially in their respective areas of inquiry, as interviewee 3 stated: *"It perhaps meets the need to to engange more deeply with the subject and to expand one's knowledge"* (ep. interview 3, Pos. 24). Intrinsic motivation emerged as a driving force in this context, as students took ownership of their learning experience by selecting, planning and carrying out their research, giving them a sense of agency.

Many participants also highlighted the individualised nature of this specific IBL approach, which allowed them to pursue knowledge that resonated with their personal interests and values, making the acquired knowledge personally meaningful. This aspect was particularly noteworthy as it not only contributed to knowledge retention, but also sparked curiosity about possible future avenues of study and exploration. The role of teachers as coaches, available for guidance throughout the process, was highlighted as a crucial aspect in this regard.

Everyday Relevance: Making Climate Change Tangible, Embracing Errors, and Critical Media Literacy

IBL helped many students connect often abstract climate-related concepts with real-world events, making the climate crisis more tangible and understandable. Research into climate phenomena and direct experiences contributed to a deeper connection with this global issue. Participant 3 noted, *"It became more practical. Away from this incredibly numrical theory, towards the human relation"* (ep. interview 3, Pos. 14).

Some interviewees also emphasised the importance of recognising that not reaching a final conclusion – whether in research or in reflection on climate change – is also a valid outcome and that failure is inherent to inquiry. Respondent 4 mentioned for example that they made mistakes during the research process and learned from them, which is consistent with the concept of embracing mistakes as a means of learning (ep. interview 4, Pos. 38). Furthermore, few participants became more critical consumers of media coverage of climate change, evaluating news and information through a more informed and reflexive lens as highlighted in the following: *"It's really a bit more of directing the focus of your perspective when you're reading the news or something"* (ep.

interview 5, Pos. 48).

5.2 RQ2: Experiences Acquired through Inquiry-Based Learning during the Seminar

This study aimed to uncover the experiences concerning characteristic implementation principles gained by pre-service teachers through IBL and how these experiences supported their ability to realise this approach in future classroom settings.

Supportive Learning Environment: Student-Centered Approach with Autonomy and Self-Directed Learning

Many participants valued the collaborative nature of the learning process, where they could work with their peers and seek guidance from lecturers when needed. It fostered a trusting and collaborative atmosphere in which students felt a sense of equality with their teachers. Participants acknowledged that the traditional role of the teacher as the sole provider of knowledge was shifting to that of a facilitator in the learning process. Respondent 2 stated in this context: *"In our case, I found it very pleasant to think about it together and since you were always very supportive"* (ep. interview 2, Pos. 22). This shift was seen as necessary for the effective implementation of IBL, which places students at the centre of their learning journey.

The reduced hierarchy within the small groups facilitated an environment conducive to IBL, in which students are actively engaged in the learning process and take on more autonomous roles. Participants valued the autonomy they were given and the opportunity to explore topics independently: "*So we did a lot on our own and that was also the great opportunity and help to first do this from the pupils' point of view*" (group discussion, Pos. 24).

Characteristics of Research: Peer-Feedback, Dealing with Complexity, Uncertainty, and Ambiguity, and the Challenge of Formulating Research Questions

Open teaching methods, reflection and peer feedback sessions played a central role in shaping the learning experiences of the participants. The dialogue and exchange of ideas that took place during the reflection and peer-feedback sessions were instrumental in challenging preconceived notions and encouraging collaboration and perspective shifts, which are core features of any research process. Respondent 1 mentioned for example: *"Reflection sessions, like the last one we had, or again in between, where we also gave peer feedback. These would be moments where we could perhaps initiate a change of perspective in an open exchange with the peers"* (ep. interview 1, Pos. 71).

Another aspect of the findings is the development of skills and attitudes related to dealing with complexity, uncertainty and ambiguity. As interviewee 1 pointed out, engaging in interest-based independent work and learning can lead to a deeper understanding of the subject matter and trigger a transformative experience (ep. interview 1, Pos. 13, 64). Through IBL, the pre-service geography teachers learned to navigate the complexities of climate change and to accept uncertainty as an inherent part of scientific inquiry.

It is important to note, however, that the seminar also presented challenges, particularly in the formulation of research questions. Participants recognised the need to refine this skill for their future teaching careers when helping their students to formulate their own research questions, as the following quote illustrates: "*Finding the question and that was*

definitely a thing that was a difficulty and that definitely stuck" (ep. interview 5, Pos. 10).

Overall Valuable Experience

After experiencing a research cycle and reflecting on it from a didactic perspective, the participants recognised the potential for transferring their IBL experiences to their future teaching careers and beyond as the following quote from Submission 3 illustrates: *"Transfer processes of what is experienced and learned from the research process into other areas of life are possible"* (reflection 3, Pos. 26). They emphasised the importance of adapting this approach to different levels of learning within a classroom. Transferring the knowledge and skills acquired during the seminar to other aspects of their teaching practice was seen as both feasible and valuable.

5.3 RQ3: Perceptions of Climate Science

The third research question aims to investigate the differentiation of pre-service geography teachers' perceptions of climate science. Initially, some participants believed that climate science was primarily driven by quantitative data. However, the seminar challenged this notion, as evidenced by one participant's observation: *"That's what I expect from climate research in particular, that it's actually very precisely data-based [means quantitative] and relatively little empirical-based [means qualitative]"* (ep. interview 1, Pos. 21). This shift in perception demonstrates the seminar's role in broadening their views on the nature of climate science.

Understanding the Research Process: Research Cycles, Access to Data, Awareness of Biases, and Limits of Science

The seminar played a pivotal role in enhancing participants' understanding of the research process. They acknowledged an enhanced transparency of how scientific processes and research cycles work and how researchers approach a topic of interest. The seminar also contributed to some participants' understanding of the accessibility of climate research. Initially, they had limited awareness about their access to data sources and research materials. Participant 2 emphasized the change, stating, *"I think we saw that we have access to more data than we actually think"* (reflection 2, Pos. 17). They not only became acquainted with data collection methods and analysis techniques but also learned about the iterative nature of research. They recognized that research often involves continuous revision and refinement, and that each finding can lead to further questions and investigations. This perspective on research processes was exemplified by interviewee 2: *"With regard to the subjectivity of such research, I think I have already come to the point where I have really noticed, especially with interviews or questionnaires and so on, how subjective the whole thing is and how much the researcher also has it in his hands to evaluate it"* (ep. interview 2, Pos. 57).

During the seminar, participants gained insights into the potential biases inherent in scientific research. They came to realize that science is not immune to subjectivity or external influences. This awareness can contribute to a more nuanced understanding of scientific knowledge, as illustrated by Participant 6: "*So this knowledge of what actually lies behind it has become much better, much more differentiated*" (ep. interview 6, Pos. 18).

Approachability of Climate Science: Bridging Theoretical and Practical Knowledge, Self-Efficacy and Perception of Researchers

Many participants also acknowledged the seminar's role in bridging the gap be-

tween theoretical knowledge and practical research skills. While they had prior exposure to theoretical aspects in their academic studies, practical research remained largely uncharted territory. Participant 4 expressed this transformation: *"So especially when I thought of research before, it was so unattainable to tackle it myself and I think it did make it more approachable"* (ep. interview 4, Pos. 14).

Additionally, the seminar had a positive impact on participants' perceived self-efficacy regarding their ability to engage with climate change research. This boost in self-confidence, coupled with the development of group-efficacy, served as a crucial foundation for effective collaborative IBL.

Furthermore, the seminar led to shifts in participants' perceptions of researchers. They transitioned from viewing researchers as infallible experts to understanding them as individuals who grapple with uncertainties and limitations in their work. Participant 6 captured this transformation: *"So, this big construct of science that you always thought was only done by Master's students or prospective professors or something. It's such a big distant thing that it's become very close"* (ep. interview 6, Pos. 60).

5.4 RQ4: Strengthening Dispositions to Act in the Context of Climate Change

The study set out to examine the extent to which a seminar, utilizing the IBL approach on climate change, could contribute to strengthening the dispositions of pre-service geography teachers to act in the context of climate change.

Knowledge-Action Gap: Confidence Dealing with Climate Change, Structural Responsibility

Deep engagement with the seminar content led to personal change for some participants. They began to question their own behaviour and some considered ways to make more environmentally responsible choices. Some participants reported tangible changes in their daily lives as a result of their seminar experience. Examples include changes in travel habits to reduce carbon footprints or meat consumption patterns, demonstrating that deep engagement could potentially translate into concrete action (ep. interview 1, Pos. 47; ep. interview 6 Pos. 26).

However, the study also highlighted the persistent gap between knowledge and action. Despite their increased understanding of climate change, some participants acknowledged a disconnect between what they know and what they do. This knowledge-action gap extended beyond the individual level, raising questions about society's collective responsibility to bridge this gap. This can be illustrated by the following excerpt by interviewee 5: *"I think you can see that there has been very little change over a very long period of time and that actually speaks more to the fact that you have a small part in the whole thing only"* (ep. interview 5, Pos. 69).

This links to another finding, the shift in participants' confidence in their perceived ability to deal with climate change. Initially, many expressed optimism, but as they engaged in IBL and delved deeper into the complexity of the issue, their confidence waned, as the following quote from interview 4 shows: *"The more I looked into the subject and the more I was in contact with people, I then rather thought I had fallen back into my pessimistic initial attitude"* (group discussion, Pos. 198). This awareness also led to a recognition of structural responsibility and the importance of collective action in addressing climate

change.

Closing the Gap: Multiplier Effect, Reduction in Psychological Distance, Emotional Engagement, Sense of Responsibility

Many participants recognised the potential for a multiplier effect. Their involvement in the seminar had the potential to create a ripple effect, amplifying the impact of their own awareness. Some reported that the research alone made them feel like agents of change, as the following illustrates: *"So the examination of the topic and the implementation of the research may already lead to consequences or new considerations for some people. So now, as here, for example, in the form of an interview. Depending on what questions are asked, this may also trigger a reflection discussion in an interview partner, which already leads to a change"* (ep. interview 2, Pos. 51).

They also emphasised the importance of clear, fact-based communication and the need to avoid moralising or preaching. Effective communication, they recognised, was key to conveying the urgency and importance of climate issues to others. Interviewee 2 for example said: *"[That one] rather manages to convince someone on a factual level or at least to make it clear to everyone how the situation is and so on, and doesn't somehow start swinging the moral authority there*" (ep. interview 2, Pos. 47).

Engaging in research in their own region, IBL reduced the psychological distance participants felt towards climate change. They began to see the issue as more proximate, immediate and relevant to their lives as illustrated in the following: *"So I think you get a much more concrete connection to climate change, especially if you haven't dealt with it so much before, and accordingly I can very well imagine that it also favours concrete action"* (ep. interview 6, Pos. 26). Some participants reported experiencing a heightened emotional connection to climate change as they delved deeper into its complexities. This emotional depth served as a powerful motivator, generating a sense of concern and urgency. This change often led to a heightened sense of responsibility, although some participants already perceived a heightened sense of responsibility due to previous academic courses.

6. Discussion

This chapter first discusses the findings presented in previous chapters, then draws on the limitations of the study while outlining further inquiry and finally acknowledges the positionality of the author.

6.1 Discussion of Findings

The findings from RQ1 emphasise the impact of IBL on pre-service geography teachers. They underline the importance of IBL not only as a pedagogical approach but also as a transformative educational experience aligning with previous findings (Schulz, 2010). The results indicate a development of enhanced communication skills about climate change, a broadened interest and knowledge base, and increased everyday relevance, which may lead to a more realistic risk perception and certainty concerning climate change (C. Shaw et al., 2016). These outcomes are consistent with some of the demands of CCE, which often requires individuals to engage in complex, evidence-based discussions and to have a comprehensive understanding of the issue (Akaygun & Adadan, 2021; Corner et al., 2015; Stevenson et al., 2017). Furthermore, the reported changes in attitude are essential for pre-service teachers to create a classroom environment where students

feel comfortable exploring complex topics without fear of failure. However, it remains debatable whether such an approach leads to a lasting transformation or if the impact is temporary, fading once participants re-enter more traditional educational settings. Additionally, the effectiveness of IBL may be limited by institutional constraints, such as curriculum rigidity or assessment-driven learning environments, which do not always align with IBL methods (Brumann et al., 2022).

RQ2 explored the experiences of the pre-service geography teachers in the seminar and their implications for future teaching. By exposing students to different perspectives and alternative teaching approaches, the seminar encouraged them to rethink their role as future educators. The benefits of a supportive learning environment and a better understanding of the characteristics of research, as the data suggests, underline the potential of IBL in teacher education. These experiences are also consistent with the principles of IBL, emphasising the importance of active student engagement, autonomy and collaboration (Justice et al., 2009; Mieg, 2019). Nevertheless, it could be argued that close-to-science IBL can be resource-intensive and difficult to implement effectively in larger and institutionalized classroom settings. Furthermore, the open-ended nature of IBL could lead to unequal learning outcomes, as students with different levels of prior knowledge or motivation may benefit unequally from such an approach (Kotuľáková, 2021; Kováčová et al., 2024).

The impact of IBL on participants' perceptions of climate science investigated in RQ3 is promising. The shift from a quantitative, data-centred view to a broader understanding of the research process is particularly notable. There was a shift in their conception of climate science, giving students a better understanding of the research process and making climate science more accessible, moving it beyond an abstract concept. They not only developed a more nuanced researcher's mindset but also developed crucial research competencies that are in line with the literature (Wessels et al., 2019). The seminar discussions and activities prompted them for example to critically assess the role of biases, both conscious and unconscious, in shaping scientific findings. However, the question arises whether such a constructivist approach might inadvertently lead to relativism, where scientific consensus is seen as just one of many possible perspectives. Given the politically charged nature of climate science, there is a risk that an overemphasis on questioning research processes could unintentionally lend credibility to climate change denialism or skepticism (Busch, 2021). All in all, the findings suggest though that such an IBL seminar enables participants to effectively communicate the nuances of climate science and engages students in meaningful scientific inquiry, which is deemed important for climate science education in the 21st century (Brooks, 2011; Howarth et al., 2020).

RQ4 highlights the potential development of participants' dispositions to act on climate change. The perceived deeper understanding of climate change can firstly lead to a more nuanced perspective on the topic. The reported awareness of the knowledge-action gap and structural responsibility highlights the broader societal implications of CCE through IBL. By recognising this gap, future educators can play a key role in shaping the collective response to climate change (Lamb et al., 2020). The potential of IBL to bridge the gap also emerged from the data through

the multiplier effect, reducing the psychological distance, fostering emotional engagement, and cultivating a sense of responsibility. All of which are important factors to enable climate action as findings from previous studies suggest (Hamann et al., 2016; Rockström et al., 2023). Despite these benefits, the extent to which educational interventions can truly drive climate action is debatable. While fostering awareness and engagement is crucial, systemic and structural barriers, such as economic constraints and political inertia, may ultimately limit the ability of individuals to enact meaningful change (Kollmuss & Agyeman, 2002). Furthermore, emotional engagement with climate issues can sometimes lead to anxiety or feelings of helplessness, potentially counteracting the intended empowerment of IBL approaches (Pfautsch & Gray, 2017).

6.2 Limitations and further Inquiry

The seminar can be regarded as a learning environment that fosters opportunities for developing multiple competences. Consequently, not all students reported the same outcomes, and the results should be interpreted as indicative potentials of close-to-science IBL in a university context. The small sample size may have influenced the outcomes and limits the generalizability of findings to larger populations. There may also be a selection bias due to the seminar being part of an elective module, potentially leading to participants who are already interested in the topic. The results are context-specific to this seminar and may not be applicable to all pre-service geography teachers or educators in different disciplines or with other subject combinations beyond German and English. Furthermore, it remains unclear whether the perceived potentials will be translated into actual classroom practice. The analysis was carried out by the author alone, i.e. no consensual coding was carried out and no inter-coder reliability was calculated. Moreover, participants may have provided socially desirable responses rather than fully authentic reflections. To mitigate this bias, participants were informed that the interviews and discussions were not part of the course assessment, and the issue of social desirability was explicitly addressed. Nevertheless, it cannot be entirely ruled out. In addition, the study does not allow for definitive causal claims, as no control group was included.

While this qualitative study provides valuable insights into the impact of IBL on pre-service geography teachers' perceptions and experiences in the context of CCE, there are several areas of potential further inquiry. It would be beneficial to conduct longitudinal studies to explore the long-term impact of IBL on these pre-service teachers. Comparative studies could also be conducted to assess the effectiveness of IBL in CCE compared to traditional pedagogical approaches. Exploring how the impact of IBL on CCE varies across different cultural and educational contexts would be valuable, given this study only focused solely on the teacher education in Augsburg, Bavaria, Germany.

6.3 Positionality

This section provides a reflexive account of the author's background and positionality, in order to contextualise the study, according to Kaufmann (2018). The author benefits from a tuition-free education, current financial stability, a previous bachelor's degree and a state teaching qualification. The author has relatively easy access to disciplinary knowledge, facilitated by concurrent doctoral research in CCE. Importantly, the participants in this study were students enrolled in a course

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These circumstances resulted in an asymmetry of knowledge and authority during group discussions and interviews, potentially leading to power-related biases. These may encourage students to align their perspectives with the instructor's expectations, thereby limiting critical engagement and reinforcing existing academic hierarchies. Furthermore, students with greater confidence or prior knowledge may dominate discussions, introducing participation bias and marginalising less experienced voices.

7. Conclusion

The results of this study demonstrate the potential impact of Inquiry-Based Learning (IBL) in the context of Climate Change Education (CCE). Pre-service geography teachers not only acquired valuable knowledge, but also developed essential skills, attitudes, and dispositions that can empower them to act on climate change. This transformation may have a trickle-down effect, influencing future generations of students in the geography classroom. The IBL seminar provided a transformative learning space for future educators to meaningfully engage with CCE. The seminar followed a structured yet flexible approach that combined knowledge dissemination, interactive learning, and iterative research development. Critical success factors included ongoing peer feedback, reflective discussions on both research progress and didactic implications, and a strong emphasis on student-driven inquiry. By integrating theory, practice, and critical reflection, the seminar effectively fostered a deeper understanding of climate change and geographical research methods, key components of a climate science literacy (US Global Change Research Program, 2009).

Accordingly, greater awareness of the

potential of such approaches should be raised among policymakers, curriculum designers, and teacher educators to explore a deeper integration of CCE through IBL, as this approach integrates many of the demands needed in future education. As an initial step, institutions should create time and space for pre-service teachers to engage in open, collaborative, and research-oriented learning environments. The alignment between theoretical knowledge and practical research skills through close-to-science IBL instruction should be a key consideration in this context too.

Ultimately, the results of this study underscore the importance of IBL in equipping future educators to address the complex challenges of the 21st century – both in their own professional practice and by inspiring their students to do the same.

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